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ENGINEER VICE-ADMIRAL SIR HENRY J. ORAM K.C.B., F.R.S.
PRESIDENT

Frontispiece

THE JOURNAL

OF THE

INSTITUTE OF METALS

Volume XI

EDITED BY

G. SHAW SCOTT, M.Sc.

SECRETARY

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LONDON
PUBLISHED BY THE INSTITUTE OF METALS
CAXTON HOUSE, WESTMINSTER, S.W.
1914

THE INSTITUTE OF METALS

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Engineer Vice-Admiral Sir H. J. ORAM, K.C.B., F.R.S., London.

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THE INSTITUTE OF METALS,
CAXTON HOUSE, WESTMINSTER, S.W.

June, 1914.

CONTENTS.

SECTION I.—MINUTES OF PROCEEDINGS.

Contents

vii

SECTION III.—MEMORANDUM AND ARTICLES OF ASSOCIATION, AND LIST OF MEMBERS.

LIST OF PLATES.

Frontispiece : Engineer Vice-Admiral Sir HENRY J. ORAM, K.C.B.. F.R.S., President.

CORRIGENDA.

Vol. X., Frontispiece, *for* " de Beffroi" *read* " du Beffroi."
„ „ p. 93, lines 41 and 43, *for* " lead-tin " *read* " tin."

THE INSTITUTE OF METALS

MINUTES OF PROCEEDINGS.

ANNUAL GENERAL MEETING.

The Annual General Meeting of the Institute of Metals was held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W., on Tuesday and Wednesday, March 17 and 18, 1914, Professor A. K. Huntington, Assoc.R.S.M., the retiring President, occupying the chair on Tuesday, March 17, prior to the declaration of the result of the ballot for the election of officers for the year 1914. Afterwards, and on Wednesday, March 18, the chair was occupied by the President, Engineer Vice-Admiral Sir Henry J. Oram, K.C.B., F.R.S.

The Secretary (Mr. G. Shaw Scott, M.Sc.) read the minutes of the previous meeting held at Ghent, Belgium, on August 28 and 29, 1913, which were found to be a correct record, and were signed by the Chairman.

Death of Mr. W. H. Johnson, Vice-President.

The President said that it was with very much regret that he had to announce the death of one of the Vice-Presidents of the Institute, Mr. W. H. Johnson. Mr. Johnson was well known to all the members; he attended most of the meetings of the Institute from its commencement, and was very largely responsible for its formation. In the early days of the Institute he acted as its Honorary Secretary. He took an immense amount of interest in it, and did a great deal of unassuming work for it, especially at the beginning. Mr.

A

Johnson's death was a real loss, not only to the Council, but he was quite sure to all those members who knew him.

REPORT OF COUNCIL.

The SECRETARY read the following Report of the Council upon the work of the Institute during the year 1913 :—

THE Council have pleasure in reporting that the year 1913 witnessed considerable and important advances in the Institute's activities, notably in the direction of the first foreign meeting and the presentation of the Second Report to the Corrosion Committee.

THE ROLL OF THE INSTITUTE.

The number of Members on the roll of the Institute on December 31, 1913, was as follows:—

Honorary Members	3
Ordinary Members	604
Student Members	19
Total	626

The following table shows the development that has taken place since the foundation of the Institute in 1908 :—

	Dec. 31, 1908.	Dec. 31, 1909.	Dec. 31, 1910.	Dec. 31, 1911.	Dec. 31, 1912.	Dec. 31, 1913.
Fellows	...	...	1	1	1	...
Honorary Members .	...	1	3	3	4	3
Ordinary Members .	350	492	524	555	578	604
Student Members . .	5	12	23	27	23	19
Total . . .	355	505	551	586	606	626

The Council regret to have to record the death during 1913 of the only Fellow of the Institute, the late Sir W. H. White, K.C.B., F.R.S., a memoir of whom, contributed by Engineer Vice-Admiral Sir H. J. Oram, K.C.B., F.R.S., appeared in Volume IX. of the Journal of the Institute.

The Council have also to record with regret the deaths of Mr. G. Matthey, F.R.S., an Honorary Member, and of the following four members: Mr. A. C. Claudet, Assoc.R.S.M.; Monsieur A. A. F. Corin ; Mr. C. H. Gadsby ; and Mr. A. E. Rowland.

GENERAL MEETINGS.

During the year 1913 two General Meetings were held. For the first time the Annual General Meeting was held in the spring instead of in January. This meeting took place in London on March 11 and 12, when the newly-elected President, Professor A. K. Huntington, Assoc.R.S.M., occupied the chair, and delivered his Inaugural Address. On March 12 the following papers were read and discussed :—

1. "Corrosion of Aluminium." By G. H. BAILEY, D.Sc., Ph.D. (Kinlochleven, Argyll).
2. "The Quantitative Effect of Rapid Cooling on Binary Alloys." By G. H. GULLIVER, B.Sc. (Edinburgh).
3. "Microstructure of German Silver." By O. F. HUDSON, M.Sc. (Birmingham).
4. "The Corrosion of Distilling Condenser Tubes." By ARNOLD PHILIP, B.Sc., Assoc.R.S.M. (Portsmouth).
5. "Practical Heat Treatment of Admiralty Gun Metal." By H. S. PRIMROSE (Ghent, Belgium) and J. S. G. PRIMROSE (Ipswich).
6. "Metal Filament Lamps." By ALEXANDER SIEMENS (London).

The Autumn Meeting was held abroad for the first time, taking place at Ghent, Belgium, on August 28 and 29. It was well attended, and excellent arrangements were made by the Honorary Local Secretary, Monsieur V. Renaud, to whom, as a token of their appreciation of his services, the Council subsequently made a suitable presentation. The Rector of the University of Ghent, Monsieur Schoentjes, attended the opening meeting, and gave an address of welcome; the second day's proceedings included an official welcome by Sir Cecil Hertslet, His Majesty's Consul-General for Belgium.

The following papers were presented at the Ghent meeting :—

1. Second Report to the Corrosion Committee. By G. D. BENGOUGH, D.Sc., M.A., and R. JONES, B.Sc. (both of Liverpool University).
2. "A Further Study of Volume Changes in Alloys." By J. H. CHAMBERLAIN, M.Sc. (Birmingham).
3. "The Micro-Chemistry of Corrosion. I. Some Copper-Zinc Alloys." By CECIL H. DESCH, D.Sc., Ph.D., and S. WHYTE, B.Sc. (both of Glasgow University).
4. "Metallographical Researches on Egyptian Metal Antiquities." By H. GARLAND (Cairo).
5. "The Specific Volume and Constitution of Alloys." By W. M. GUERTLER, Ph.D. (Berlin).
6. "The Copper-Rich Kalchoids (Copper-tin-zinc Alloys)." By Professor S. L. HOYT (University of Minnesota, U.S.A.).

7. " A Method of Improving the Quality of Arsenical Copper." By F. JOHN-
    SON, M.Sc. (Birmingham).
8. " The Influence of Phosphorus on Some Copper-Aluminium Alloys." By
    Professor A. A. READ, M.Met. (Cardiff).
9. " The Annealing of Gold." By T. K. ROSE, D.Sc., Assoc.R.S.M. (The Royal
    Mint, London).
10. " The Intercrystalline Cohesion of Metals." Second Paper. By W. ROSEN-
    HAIN, D.Sc., F.R.S., and D. EWEN, M.Sc. (both of the National Physical
    Laboratory, Teddington).
11. " The Determination of Oxygen in Copper and Brass." By T. WEST, M.Sc.
    (Montreal).

In the evening of August 29 a Reception was given at the Town
Hall, Ghent, by the Bourgmestre, M. Braun. In the afternoon of
August 28, members visited the works of Messrs. Carels Frères and
of Messrs. Van der Kerchove. The following afternoon was spent
in the Ghent International Exhibition, the party being under the
guidance of Monsieur Renaud.

The Council desire to record their indebtedness to the Ghent Ex-
hibition authorities for their courtesy in allowing the Autumn
Meeting to be held in their buildings ; and also to the Council of the
Institution of Mechanical Engineers for a similar courtesy on the
occasion of the Annual General Meeting of the Institute in March.

COMMITTEE MEETINGS.

The Council has held monthly meetings, and the four standing
committees, known as the Corrosion Committee, the Finance and
General Purposes Committee, the Library and Museum Committee,
and the Publication Committee, have met regularly during the
past year, and several occasional committees have been appointed
by the Council for the consideration of special matters. The Ab-
stracts Sub-Committee has been dissolved, its functions devolving
upon the Publication Committee.

CORROSION COMMITTEE.

A Second Report was received from the Committee's Investigator,
and was read at the Ghent meeting. This Report contained an
account of a large amount of experimental work.

Since the publication of the Report, experimental work has been
actively resumed and a number of improvements have been carried
out in the apparatus employed. A copper-aluminium alloy and
phosphor-bronze have been added to the list of alloys previously

studied, but work on Muntz metal has been discontinued. An elaborate study is being made of the mode of action of estuarine waters, which practical experience has shown to be particularly harmful. Work is being continued on the subject of electro-chemical protection. A salaried assistant to the Investigator has recently been appointed, in order that the experimental work may be pushed on more rapidly, Mr. W. E. Gibbs, M.Sc., having been selected for the position.

The Committee are very grateful for the substantial financial assistance which several donors have provided to enable the work to be carried on. For its further continuance and development, however, additional sums are required; their receipt will be warmly appreciated by the Committee.

THE BEILBY RESEARCH PRIZE.

The Investigator to the Beilby Research Committee—Dr. Cecil H. Desch—has during the past year devoted his energies to the compilation of a review of the literature dealing with the subject of the solidification of metals from the liquid state, and is presenting a Report of his investigations at the present meeting.

NOMENCLATURE COMMITTEE.

The Nomenclature Committee, appointed in 1912 as a result of a suggestion contained in Dr. Rosenhain's Paper on "A Note on the Nomenclature of Alloys," read at the Annual General Meeting in January 1912, met several times during the year, and has formulated many useful suggestions which are being laid before the members of the Institute for their discussion at the present meeting.

MAY LECTURE.

The Council did not find it possible to arrange for a May Lecture to be given in 1913, but they have pleasure in stating that Professor E. Heyn, of Berlin, has agreed to deliver the 1914 May Lecture, his subject being "Internal Strains in Cold Wrought Metals, and some troubles caused thereby." The Council have decided that the May Lecturer will in future receive an honorarium of £10.

BIRMINGHAM LOCAL SECTION.

The third session of the Section has been very successful, both as regards meetings and finance.

The membership at the close of the session was as follows :—

Members .	.	.	.	.	.	.	59
Associates	.	.	.	.	.	.	21
Total		.	.	.	80

The membership last year was 72—51 Members and 21 Associates. There has therefore been an increase of 8 Members during the year.

Six meetings were held during the session :—

1912.
Oct. 22. Chairman's Address.   By Professor T. TURNER, M.Sc.
Nov. 26. Paper on " The Microstructure of German Silver."   By O. F. HUDSON, M.Sc.
Dec. 10. Discussion on " The Treatment of Waste Products."
1913.
Jan. 23. Notes on " Copper and Copper Alloys."   By F. JOHNSON, M.Sc.
Feb. 18. Paper on " Annealing Muffles."   By C. H. WALL, M.I.M.E.
April 15. Paper on " The Conductivity of Metals and Alloys."   By A. G. C. GWYER, B.Sc., Ph.D.

Most of the papers read at the meetings were illustrated by lantern slides.

The Discussion on December 10 was the occasion of an interesting and successful gathering.

The average attendance was 23 Members and Associates, and 7 Visitors.

Six Committee Meetings have been held during the session, the average attendance being 8 Members.

The First Annual Dinner was held on May 15 ; it was well attended and was very successful.

The Section has received permission from the Council of the Institute to elect Honorary Associates, and Mr. A. H. Hiorns was unanimously elected the first Honorary Associate on January 23, 1913.   Mr. Hiorns, who has recently retired from the responsible position of head of the Metallurgical Department of the Birmingham Technical School, is well known as a teacher, author, and investigator.

The fourth session, 1913–1914, commenced in October.

PUBLICATIONS.

Two volumes of the Journal were published in 1913, Volume IX. being issued in June and Volume X. in December.   The sales of the Journal for the past year constituted a record, 255 volumes having been sold during that period.   This figure compares with

179 volumes for the year ended June 30, 1912, and 163 volumes for the preceding year.

LIBRARY AND MUSEUM.

Many additions to the Library and Museum were made during the past year, and these are enumerated on pp. 385–389 of the Journal, Volume X. Attention is called to the collection of lantern slides that has been started during the year as a result of contributions received from Mr. H. Garland, Member (Cairo). A list of the slides presented by Mr. Garland is given in Volume X., p. 390, and the Council will be glad to receive additional lantern slides. Gifts of books dealing with the non-ferrous metals will also be gladly received.

DELEGATES TO CONFERENCES.

In connection with the 1915 Congress of Mining, Metallurgy, Applied Mechanics, and Practical Geology, the Council have appointed as their representatives on the Publications Committee of the Congress, Sir W. E. Smith, C.B., and Dr. W. Rosenhain, F.R.S. The Council have guaranteed the sum of £50 towards the expenses of the Congress. Other invitations to appoint delegates have been received by the Council in connection with the following, and the undermentioned appointments have been made :—

(a) Engineering Standards Committee, Automobile Parts : Professor A. K. Huntington, Assoc.R.S.M.

(b) Sir William White Memorial Committee : Sir Gerard A. Muntz, Bart. ; Professor W. Gowland, F.R.S., Assoc.R.S.M. ; Professor A. K. Huntington, Assoc.R.S.M. ; and Dr. W. Rosenhain, F.R.S.

(c) Institution of Mechanical Engineers, General Engineering Research Committee : Professor A. K. Huntington, Assoc. R.S.M. ; Mr. L. Sumner, M.Sc.

ANNUAL DINNER.

The Fourth Annual Dinner was held on March 11, and there was an attendance of about 150, amongst whom were many distinguished guests, including the Presidents of allied societies and Sir H. F. Donaldson, K.C.B. ; Sir J. Alfred Ewing, K.C.B., F.R.S. ; Colonel H. C. L. Holden, C.B., F.R.S. ; and Professor W. C. Unwin, F.R.S.

Signed on behalf of the Council,

A. K. HUNTINGTON, *President*.

H. J. ORAM, *Vice-President*.

January 29, 1914.

REPORT OF THE HONORARY TREASURER.

(Professor THOMAS TURNER, M.Sc.)

For the Year ending June 30, 1913.

It is gratifying to be able once again to record a satisfactory result on the financial side of the work of the Institute. The balance at the beginning of the financial year was £563 10s. 11d.; this was increased during the year to £699 6s. 3d., which latter sum included £50 put aside to meet a future liability in connection with Dr. Beilby's prize. The actual addition to the reserves of the Institute was therefore £85 15s. 4d., which though less than in the previous year is still satisfactory. Owing to additional responsibilities undertaken by the Council the expenditure gradually increases year by year. Such additional expenditure means better value to members, and will doubtless be met by increased membership in future. Since the close of the financial year now under review a substantial addition has been made to the funds at the disposal of the Corrosion Research Committee. This welcome increase will permit of the continuance and extension of the valuable investigation which is in progress.

TREASURER'S ACCOUNT OF RECEIPTS AND PAYMENTS FOR YEAR ENDING JUNE 30, 1913.

RECEIPTS.

	£ s. d.	£ s. d.
To Balance brought forward from last Account—		
Lloyd's Bank Limited—		
Deposit Account	£364 15 2	
General	180 6 5	
Cash in hand of Secretary	13 8 10	
" " Treasurer	5 0 6	£563 10 11
„ Subscriptions (including Entrance Fees)	£1278 2 7	
„ Sales of Journal	216 9 4	
„ Sale of Dinner Tickets	43 16 0	
„ Miscellaneous Receipts	3 3 7	
„ Bank Interest, less Charges	4 9 5	
„ Interest on Deposit Account	10 7 2	1556 8 1
„ Donation from Dr. Beilby for Prize	£100 0 0	
„ „ Sir Henry Wiggin for Library	10 10 0	110 10 0
„ CORROSION FUND—		
Balance as on June 30, 1912	£47 7 6	
Subscriptions	26 16 0	
	£74 3 6	
Less—Amount expended on		
Corrosion Plant £43 6 6		
" Expenses of Working 1 7 8	44 14 2	
	£29 9 4	
Amount due to Dr. Bengough	6 6 1	35 15 5
		£2266 4 5

PAYMENTS.

	£ s. d.	£ s. d.
By Expenses of Meetings		£4 11 6
„ „ Journal		576 18 4
„ MANAGEMENT EXPENSES—		
Secretary's Salary and Commission	£370 0 0	
Rent, Rates, &c.	162 9 9	
Printing and Stationery	47 6 8	
Clerical Assistance	126 4 6	
Postages, Traveling Expenses, and Sundries	77 4 1	783 4 3
„ Expenses of Dinner	£65 13 2	
„ Repairs, &c.	14 7 0	
„ Furniture Purchased	30 7 6	
„ Subscriptions, &c.	6 1 0	
„ Beilby Prize—Dr. C. H. Desch	50 0 0	166 8 8
„ Balance forward—		
Lloyd's Bank Limited—		
Deposit Account (Beilby Prize)	£447 12 10	
„ General	50 0 0	
Cash in hand of Secretary	187 11 9	
„ Treasurer	12 14 2	
	1 7 6	699 6 3
„ CORROSION FUND—		
Lloyd's Bank Limited	£29 0 7	
Cash in hand of Secretary	6 14 10	35 15 5
		£2266 4 5

The PRESIDENT, in formally moving the adoption of the Report of Council, said that it was fairly voluminous, and covered most of the ground that had been traversed by the Institute in the course of the year. He hoped that the members would be satisfied with the work which had been done during the past year, and the progress which the Institute had made. He did not think it was necessary to take up time by dilating on that work; the Report was sufficiently explicit in regard to what had been done, and the members were acquainted with the work through the medium of the Journal, if not through attending the meetings of the Institute itself.

Dr. C. H. DESCH, in seconding the motion, said that he thought that the report was very satisfactory. Although there had been a very satisfactory increase in the membership since the previous year, and a still more satisfactory increase since the beginning, he thought that members must feel that the number of persons who were directly connected with the non-ferrous metal industries of the country was much larger than the membership of the Institute, and that individual members should do their best to persuade those connected with the industry to become members of the Institute.

The PRESIDENT said that Dr. Desch had called attention to the fact that there was a very large number of people who had not yet been "roped in." The Council had rather preened itself on the fact that they had done so well since the Institute was formed. Dr. Desch was quite right, however, in saying that there was plenty of room inside the Institute for more members, and the Council hoped they would be forthcoming.

The resolution was then put and carried unanimously.

TREASURER'S REPORT.

The PRESIDENT said that as all the members had received copies of the Treasurer's Report, he thought it would be the wisest plan to take it as read, especially as the Treasurer

was unavoidably absent. At the same time he thought he would not be expressing the real feelings of the members if he did not propose a hearty vote of thanks to the Treasurer for the work he had performed on behalf of the Institute. Of all the officials of the Institute, the Treasurer had perhaps the most ungrateful task. He had to perform a good deal of his work by the use of midnight oil, and he did not appear in the glare of the footlights. The Treasurer did a great deal of useful work and received very small thanks for it, so that he thought the least the members could do on the present occasion was to express their appreciation of his services, which had been very considerable. He proposed a hearty vote of thanks to the Treasurer for his services during the past year.

The resolution was carried by acclamation.

The PRESIDENT said that in consequence of the much-regretted death of Mr. Johnson, it had become necessary to appoint another Vice-President, and the Council were quite unanimous in selecting Mr. J. T. Milton, who had done so much useful work for the Institute. Owing to Mr. Milton's numerous engagements, both in his official capacity and in connection with the Institute of Naval Architects and other Institutions, he had not been able recently to give all the time he wished to the affairs of the Institute as an ordinary Member of Council, and he expressed his wish to resign; and although the Council very much regretted Mr. Milton ceasing to be a member of Council, they could not do otherwise, in the circumstances, than accept his resignation. They thought, however, that his past services had been such that he was in every way entitled to be made a Vice-President, as a slight recognition of the sterling work he had done for the Institute. Mr. Milton was therefore asked to become a Vice-President, and although he declined at first to accept the nomination because he thought he had so little time, he (the President) could now announce Mr. Milton's acceptance of the office. One of the members of the Council, Mr. Clive Cookson, had also resigned on account of pressure of work, but the Institute had

been fortunate enough to secure the services of the Hon. Sir Charles Parsons, K.C.B., F.R.S., to fill the vacancy thus caused. That vacancy had been filled up by the Council, as it occurred before the ordinary ballot for the election of members of Council.　He was sure all the members would be gratified to know that Sir Charles was able to spare the necessary time to devote to the work of the Council of the Institute, and he asked them to confirm that election.

The meeting unanimously confirmed the appointments made by the Council.

Election of Officers.

The President called upon the Secretary to announce the result of the ballot for the election of Officers to replace the retiring President, three Vice-Presidents, and five members of Council, the list as read being as follows :—

President.

Engineer Vice-Admiral Sir H. J. Oram, K.C.B., F.R.S., London.

Vice-Presidents.

Professor H. C. H. Carpenter, M.A., Ph.D.	London.
R. Kaye Gray	London.
Summers Hunter	Wallsend-on-Tyne.

Members of Council.

L. Archbutt	Derby.
George Hughes	Horwich.
R. S. Hutton, D.Sc.	Sheffield.
W. Murray Morrison	London.
W. Rosenhain, D.Sc., F.R.S. . . .	Teddington.

Dr. T. K. Rose, in proposing a hearty vote of thanks to the Council for their services to the Institute during the past year, said the Council was a body of very distinguished men, who had given their services, most of them for years past, in building up the Institute, and bringing it to its present excellent position.　Their work during the past year had been, as usual, laborious and extremely successful.　He was quite

sure every member of the Institute felt personally indebted to the Council for the work they had done in conserving and promoting their interests. Probably their work during the past year had not been more arduous than in previous years, but it appealed to him personally more than it had done on any previous occasion, because he had realized more than ever its complete success.

Mr. G. G. POPPLETON, in seconding the motion, said that those who had been associated with the Institute from its inception knew the arduous work the Council performed. He felt sure that, as time went on, and the work became even more important, the members would recognize in a greater measure the valuable services rendered by the Council. Personally he well remembered the first and the second meetings, which the late Vice-President, Mr. W. H. Johnson, attended, and he knew the interest that gentleman took in the formation work. He was sure the members joined with the President in his expression of great regret at his death.

The motion was put to the meeting by Dr. ROSE, and carried unanimously.

The PRESIDENT, on behalf of the Council and himself, thanked the members for the very kind vote they had just passed. Owing to the position he occupied as President, he was perhaps better able to judge than anybody else the individual interest taken by the Council in the Institute, and he was able to say that all the members without exception took the very greatest interest in its proceedings. He could say without hesitation that the Institute had a Council which worked, to say the least of it, as well as the Council of any other important body in existence. It was a very great pleasure to watch the growth of such an institution, and to see that it did not flag and become difficult to manage. From the very start the Institute had made steady and consistent progress, and although Dr. Desch had just given the Council a little " dig " that they ought to move faster, he thought Dr. Desch recognized, as everybody else did, that very rapid

progress had been made. If the progress of the Institute in its earliest years were compared with that of the other Institutes in the country, as it had been in his Presidential Address, it must at once be recognized by everyone that rapid progress had been made, and that of itself showed that the Institute was really wanted, and that it was behind, rather than in front of, its time. When the Institute attained a membership of 600, some of its prominent members thought that very much progress would not be made for some years, but personally he was perfectly certain the Institute would go on increasing in numbers even more rapidly than it had done during the past two or three years. The Institute had thoroughly " caught on "; it was obtaining a good many foreign members, and he did not think there was any likelihood of any serious arrest taking place in the membership for some time.

ELECTION OF MEMBERS.

The SECRETARY read the following list of names of candidates for membership who had been duly elected as a result of the ballots taken in December 1913 and in February 1914 :—

NAME.	ADDRESS.	QUALIFICATIONS.	PROPOSERS.
Ayers, Eng. Capt. Robert Bell, M.V.O., R.N. (ret.)	15 Infield Park, Barrow-in-Furness	Engineer - Captain, Royal Navy	Sir H. J. Oram. J. McKechnie. H. B. Weeks.
Beer, Emil	120 Fenchurch St., E.C.	Metal Merchant	J. F. Sjögren. J. G. Brookbank. H. Griffiths.
Brotherhood, Stanley	Peterborough	Engineer	Sir H. J. Oram. G. G. Goodwin. F. W. Marshall.
Bryant, Charles William	Stanground House, Peterborough	Engineer	Sir H. J. Oram. G. G. Goodwin. F. W. Marshall.
Buck, Henry Arthur	" Malahide," Harrowdene Road, Wembley, Middlesex	Secretary, London Metal Exchange	P. W. Smith. H. Gardner. W. W. Letcher.
Burnett, Jacob Edward	53 Percy Park, Tynemouth	Foundry Manager	S. Hunter. C. Morehead. H. D. Smith.
Butler, Reginald Henry Brinton, B.Sc.	Box 247, Short Hills, N.J., U.S.A.	Metallurgical Engineer, Manager, U.S. Ford Co. (Aluminium Dept.)	A. K. Huntington. Sir W. E. Smith. T. Turner.

Name.	Address.	Qualification.	Proposers.
Carnt, Eng.-Com. Albert John, R.N.	"St. Bedes," Walton, Peterborough	Engineer	Sir H. J. Oram. G. G. Goodwin. J. McLaurin.
Carter, George John	Cammell, Laird & Co., Ltd., Birkenhead	Managing Director, Engineering and Shipbuilding Works	Sir H. J. Oram. G. G. Goodwin. J. McLaurin.
Clark, William Edwards	"Newnham," Holly Lane, Erdington, Birmingham	Electro-plate Manufacturer, Manager Elkington & Co., Ltd.	G. A. Boeddicker. R. M. Sheppard. L. J. Meyrick.
Clark, William Wallace	American Vanadium Co., Bridgeville, Pa., U.S.A.	Chief Chemist	B. D. Saklatwalla. H. P. Tiemann. H. O. Hofman.
Clarke, Walter G.	39 Old Broad St., E.C.	Metal Dealer	H. Gardner. W. W. Letcher. R. Francis.
Dewar, James M'Kie	Cammell, Laird & Co., Ltd., 3 Central Buildings, Westminster, S.W.	Naval Architect	Sir H. J. Oram. G. G. Goodwin. F. W. Marshall.
Evans, Ulick Richardson, B.A.	28 Victoria St., Westminster, S.W.	Consulting Electro-Metallurgist	F. W. Harbord. C. T. Heycock. A. K. Huntington.
Falk, Erik	Swedish Metal Works Co., Ltd., Westerås	General Manager, Metal Works	A. S. Sjögren. J. Echevarri. Arthur Jacob.
Fitzbrown, George, A.R.S.M.	Ditton Copper Works, Widnes	Copper Smelter	L. Sumner. W. Gowland. W. H. Merrett.
Fleminger, Reginald Edward	River Plate House, Finsbury Circus, E.C.	Contractor, interested in Alloys for Railway Use, Bearings, &c.	R. Francis. W. W. Letcher. Pitt Becker.
Gibb, Allan	29 Buckingham Palace Mansions, S.W.	Metallurgist	E. L. Rhead. W. Gowland. T. K. Rose.
Gibbs, Leonard	"Abermaw," School Rd., Hall Green, Birmingham	Brass Cased Tube Trade, Works' Manager, Britannia Tube Co.	G. Bill-Gozzard. S. M. Hopkins. C. A. Russell.
Gilley, Thomas Barter	Walker Gate, Newcastle-on-Tyne	Non-ferrous Metal Alloys Manufacturer, Man. Dir. Metallurgical Co., Ltd.	E. C. Keiffenheim. J. T. Dunn. H. D. Smith.
Gladitz, Charles	Duram Works, Hanwell, W.	Tungsten Metal Manufacturer	Sir C. A. Parsons. A. K. Huntington. Sir H. J. Oram.
Gresty, Colin (Student)	Northumberland Engine Works, Wallsend-on-Tyne	Analytical Chemist	S. Hunter. A. K. Huntington. H. J. Young.
Guernsey, The Rt. Hon. Lord	9 Sussex Square, W.	Director of Metal Works (Duram, Ltd.)	A. K. Huntington. Sir W. E. Smith. W. Rosenhain.
Hill, Eustace Carey	"Clifton House," Park Road, Coventry	Aluminium and Bronze Founder, Director and Technical Manager, Rowland Hill & Sons, Ltd.	F. W. Gower. J. Echevarri. W. M. Morrison.

NAME.	ADDRESS.	QUALIFICATION.	PROPOSERS.
Jameson, Charles Godfrey	British Aluminium Co., Ltd., Kinloch-leven, Argyllshire	Metallurgist	G. H. Bailey. W. M. Morrison. E. E. Eccles.
Main, Eng.-Com. Reuben, R.N.	86 Cavendish Drive, Rock Ferry, Cheshire	Engineer - Commander, Royal Navy	Sir H. J. Oram. J. McLaurin. J. A. Richards.
Mannell, John	G. Thomson & Co., Ltd., Aberdeen White Star Line, Billiter Square, E.C.	Superintendent Engineer	Sir G. A. Muntz. R. M. Sheppard. L. J. Meyrick.
Morison, Eng. Com. Richard Barns, R.N.	C/o Admiralty, Whitehall, S.W.	Engineer - Commander, Royal Navy	Sir H. J. Oram. G. G. Goodwin. J. A. Richards.
Nevill, Richard Walter, B.Sc. (Student)	" Clovelly," Earlsdon Avenue, Coventry	Metallurgical Chemist, Coventry Chain Co., Ltd.	T. Turner. O. F. Hudson. H. I. Coe.
Norton, Allen Bullard (Student)	The Aluminium Castings Co., Detroit, Mich.	Chemical Engineer in Research Department of Aluminium Castings Co.	A. K. Huntington. W. M. Morrison. A. Philip.
Phelps, John, M.A.	" Newcroft," Egmont Road, Sutton, Surrey	Assistant Assayer in the Royal Mint	T. K. Rose. S. W. Smith. A. K. Huntington.
Quin, Laurence Howard	3 East India Avenue, E.C.	Journalist and Publisher	H. Gardner. R. Francis. W. W. Letcher.
Randall, Eng. Lieut. Charles Russell Jekyl, R.N.	2 Furness Park Road, Barrow-in-Furness	Engineer - Lieutenant, Royal Navy	Sir H. J. Oram. J. McKechnie. H. B. Weeks.
Rasquinet, Albert	84 Rue de Froidmont, Liége, Belgium	Engineer, Société Anonyme des Usines à Cuivre et à Zinc de Liége	Sir H. J. Oram. T. Turner. W. Rosenhain.
Raworth, Benjamin Alfred, Wh.Sc., M.I.Mech.E.	36 Bedford Street, W.C.	Civil Engineer, Joint Editor of *Engineering*	W. H. Maw. Sir G. A. Muntz. W. M. Morrison.
Roberton, Charles George	12 Cavendish Park, Barrow-in-Furness	Manager, Vickers, Ltd., Barrow-in-Furness	Sir H. J. Oram. J. McKechnie. H. B. Weeks.
Ross, Archibald John Campbell	R. & W. Hawthorn, Leslie & Co., Ltd., Newcastle-on-Tyne	Engineer	Sir H. J. Oram. G. G. Goodwin. F. W. Marshall.
Sanders, Alfred	5 and 6 Warstone Lane, Birmingham	Gold and Silver Refiner and Smelter	C. H. Wilson. J. Howard Wilson. E. A. Smith.
Skelton, Herbert Ashlin	The British Aluminium Co., Ltd., Foyers, N.B.	Engineer and Manager for the British Aluminium Co., Ltd.	A. K. Huntington. W. M. Morrison. E. E. Eccles.
Speier, Leopold	Altheimer Speier & Co., Frankfurt-am-Main, Germany	Metal Merchant, Partner, Altheimer Speier & Co.	W. M. Morrison. J. Echevarri. Arthur Jacob.
Stewardson, George	Taranaki Street, Wellington, New Zealand	Brass Founder.	Sir W. E. Smith. W. Rosenhain. W. M. Morrison.

NAME.	ADDRESS.	QUALIFICATIONS.	PROPOSERS.
Taylor, Eng. Capt. Charles Gerald, R.N.	Royal Naval College, Keyham, Devonport	Engineer - Captain, Royal Navy.	Sir H. J. Oram. G. G. Goodwin. J. McLaurin.
Tyschnoff, Wsewolod	Motowilicha, Perm Gun Works, Perm, Russia	Metallurgist	Sir W. E. Smith. W. Rosenhain. Sir H. J. Oram.
Varley, John William	" Honorville," Finnemon Rd., Ideal Village, Little Bromwich, Birmingham	Mechanical Engineer	T. Turner. R. M. Sheppard. L. J. Meyrick.
Walters, William Llewellyn	5 Knole Avenue, Swansea	Chief Analyst, The British Mannesmann Tube Co., Ltd.	E. Mills. J. Corfield. R. W. G. Corfield.
Warburton, Frederick William	Duram Works, Hanwell, W.	Director of Metal Works (Duram, Ltd.)	Sir H. J. Oram. A. K. Huntington. T. Turner.
Watts, Sir Philip, K.C.B., F.R.S.	10 Chelsea Embankment, S.W.	Naval Architect, Adviser on Naval Construction, The Admiralty	Sir H. J. Oram. J. McLaurin. F. W. Marshall.
Webb, Herbert Arthur	18 Sheredan Road, Highams Park, N.E.	Mechanical Engineer and Cartridge Maker	R. F. Hartley. J. J. Edwards. E. I. Thorne.
Wilkes, Joseph	75 Hillaries Rd., Gravelly Hill, Birmingham	Metallurgist, Techical Manager, Duralumin Dept. of Electric and Ordnance Accessories Co., Ltd. (Vickers, Ltd.)	J. McKechnie. H. B. Weeks. G. A. Boeddicker.
Woollven, Rolfe Armstrong	" Fairview," Cedar Road, Sutton, Surrey	Demonstrator in Metallurgical Lab., King's College	A. K. Huntington. W. Gowland. W. H. Merrett.

The PRESIDENT said the Secretary informed him that the list of fifty names that he had just read was the biggest list that the Institute had had since its first year, and brought the membership of the Institute up to 640. Another ballot for the election of members would be held in connection with the May Lecture, and, thanks largely to their worthy President-designate, Sir Henry Oram, he was happy to say that several applications for that election had already been received. The nominations for the next election should be received not later than April 29.

ELECTION OF AUDITOR.

He had now to propose the re-election of Mr. G. G. Poppleton as the Auditor of the Institute. Mr. Poppleton had been the

Honorary Auditor from the commencement; he had been exceedingly useful, and he was sure the members could not possibly do better than re-elect him. He had very great pleasure in moving the re-election of Mr. Poppleton as the Honorary Auditor of the Institute.

Mr. G. A. BOEDDICKER, in seconding the motion, said he did so with much pleasure, as it gave him the opportunity of expressing to Mr. Poppleton, on behalf of the Birmingham Local Section, their very great thanks for the good work he had done on their behalf.

The motion was then put and carried unanimously.

INDUCTION OF THE NEW PRESIDENT.

The retiring President (Professor A. K. Huntington) said it was now his exceedingly pleasing duty to induct into the chair the new President, Sir Henry Oram.

The chair was then vacated by Professor A. K. Huntington, and taken amid hearty cheering by the President, Engineer Vice-Admiral Sir Henry J. Oram, K.C.B., F.R.S.

The PRESIDENT (Sir Henry Oram) thanked the members most sincerely for the great honour they had done him in electing him as their President. It was an honour done not only to himself, but also to the navy in which he had the honour to serve, and he assured the members he would do his best to advance the interests of the Institute during his year of office.

VOTE OF THANKS TO THE RETIRING PRESIDENT.

His first duty was the pleasant one of proposing a vote of thanks to Professor Huntington, the retiring President, for his services during his year of office. It had been his (the President's) pleasure to sit on the Council for many years, and he could therefore testify to the hard work Professor Huntington had done in the interests of the Institute. He

also had a genial manner, which was a valuable asset; in fact, it was a pleasure to serve with him. He had, therefore, great pleasure in formally proposing: "That the best thanks of this meeting be accorded to Professor Huntington for his Presidency of the Institute," a resolution which was carried by acclamation.

Professor WILLIAM GOWLAND, Past-President, in seconding the motion, said that he was sure that all the members would agree with him that their most hearty thanks were due to Professor Huntington for the very able manner in which he had conducted the affairs of the Institute during his Presidency. During that time the Institute had made very great progress, and although the membership might not have increased as Dr. Desch desired, he wished to point out that such a large accession of members annually could not now be expected as was the case in the earlier years. The Institute had on its roll a great proportion of those who took a serious interest in the subjects with which it dealt. He desired to take the opportunity of expressing his very grateful thanks to Professor Huntington for the aid that gentleman rendered him during his (Professor Gowland's) term of Presidency. Professor Huntington not only acted as President for the usual year of office, but he also acted as President during part of his (Professor Gowland's) period of office, when, owing to his long illness, he was prevented from doing what he intended to do for the Institute. Professor Huntington came forward in a very praiseworthy manner and offered to do the work for him, and whatever he did he did with all his might. He had the greatest possible pleasure in seconding the vote of thanks which Sir Henry Oram had proposed.

The resolution was then put and carried by acclamation.

Professor A. K. HUNTINGTON, in reply, cordially thanked the members for the manner in which the motion had been received, and the mover and seconder for the kind terms in which it had been placed before the meeting. He had done what little he could, and he was sure everybody else connected with the Institute was doing likewise.

INAUGURAL ADDRESS.

The PRESIDENT delivered his inaugural address, at the conclusion of which

Dr. WALTER ROSENHAIN, F.R.S., in moving "That a very hearty vote of thanks be accorded to the President for his Address," said that he knew he was voicing the feelings of everyone present when he said they had heard an Address which contained something quite unique. Sir Henry had given an inside view, as it were, of the history of one particular aspect of non-ferrous metals, a record based upon the experience of what was probably the largest user of those materials in the world. The members were not only grateful that such history had been given to the makers and users of non-ferrous metals generally for their guidance and instruction, but they were particularly proud that it should have been given to them through this Institute. The President's Address was not supposed to be discussed, but he desired to make a few informal remarks in reference to the statements the President had made as to the decreasing use of non-ferrous metals in connection with warship machinery. That was a warning which those who were concerned in the manufacture of non-ferrous metals should take very seriously to heart. Sir Henry Oram in his position was impartial ; he was equally concerned with the uses of steel and of non-ferrous metals. He (Dr. Rosenhain) shared that impartiality of position, and might therefore perhaps be allowed to comment on the point to which the President had alluded. He wished to emphasize that if the uses of non-ferrous metals were not to undergo continuous and systematic restriction and reduction in favour of a more extensive use of iron and steel, it was time for those who were interested in the non-ferrous metals to bestir themselves and see that advances were made in their materials as rapidly as, and if possible more rapidly than, the advances that were being effected in iron and steel. The subject was becoming a question of money and of commerce for those who wanted to make and sell non-ferrous alloys. One of the real lessons and points of Sir Henry's admirable

address was that the makers of those alloys should endeavour to bring them up to date, and to find out not only the best ways of using the materials which were at present in existence, but to bring up their products, by the aid of scientific methods and the means of interchange which the Institute afforded, to such a level that they could meet requirements which iron and steel could not meet. Personally he felt convinced that there was ample room for the expansion of the use of non-ferrous metals and alloys. He was not at all certain that the tendency which the President indicated, that those alloys should be used merely where steel could not be obtained, was a permanent one. He thought it was due to the fact that the development of iron and steel had gone ahead very fast, whereas the development of the non-ferrous alloys had to some extent lagged behind. Signs were not wanting, however, that better things might be looked for, and that there was not only a field for the non-ferrous metals in those places to which reference had been made, but in regard to many other requirements, which would arise increasingly in the future, which ferrous metals could never meet. He asked the members to accord a very hearty vote of thanks to Sir Henry Oram for his most valuable and interesting address.

Mr. A. E. SEATON (Member of Council) said that it was his privilege to second the resolution so ably proposed by Dr. Rosenhain. He had known Sir Henry from his youth upwards, not only as a man of considerable ability, of sound judgment, and knowledge, but as one who, when he took a thing in hand, did it thoroughly. He was quite sure that, having undertaken the Presidency of the Institute, he would follow successfully the path of previous Presidents, and maintain that character which had distinguished him through life, and in the office that he now so ably filled, and that his work here would be characterized by that thoroughness which they all delighted to see. The Institute had been particularly fortunate, he thought, in its Presidents, of whom there now had been five. They had all been distinguished men, but in quite different walks of life, and their addresses had been evidence of that fact. In the present instance Sir Henry himself had given

an address which, while differing distinctly from those of the previous Presidents, had been in no way inferior to theirs.   The address had been not only to him, but he was sure to all the members, exceedingly interesting and highly instructive.   He was not aware that the manufacturers were indebted to the Admiralty for so much relating to condenser tubes as Sir Henry had now stated.   Time was when they dared not propose very much to the Admiralty, but such had not been the case since Sir Henry had presided there.   In those older days manufacturers had to accept what was dictated to them, expected to ask no questions, and make no observations ; if they got through their tests they had cause to be satisfied. Sir Henry is distinguished by having an open mind on most subjects brought before him for consideration.   He had had the pleasure of discussing many problems in the past with the President, who dealt with them, not only from an academic, but from a manufacturer's point of view, and had always found that Sir Henry possessed the same open and ingenuous mind that he had displayed in his inaugural address.   It was not for the members to discuss the address in the same way as a paper read before the Institute, but he hoped he would be allowed to trespass, as Dr. Rosenhain had done, in making a few remarks about it.   Time was when manufacturers looked upon lead in any of their compositions as something very terrible.   If a metal ingot contained a trace of lead it often meant trouble, and manufacturers used to find it a very difficult thing to get commercial copper entirely free from lead ; even when they bought the best Silesian spelter the chemist at Portsmouth was sure to report there was lead in the bronze or brass casting ; consequently he came to the conclusion that there must be lead in everything, and that it was no use attempting to get anything without some small fraction of lead in it.   That lead in the smallest quantity in a bronze alloy was looked upon as a positive evil was the rule, but now they find that if the Admiralty had not been so very particular about lead they might have had long ago condenser tubes superior to common ones because of the lead in them. Whether the results would then have been more satisfactory or not he did not know ; judging, however, by those obtained

by the Research Committee, it was at any rate hardly doubtful. He desired to express his personal thanks to Sir Henry for having taken the office of President, and for having favoured them with such an interesting and instructive address. He knew he was voicing the feeling of the engineering world at large when he said it was a great advantage to the Institute that a gentleman should occupy the chair who could consider such questions as came before it, not only from the academic point of view natural to our professors, but also from that of the practical metallurgist who had to produce material to pass the Admiralty and other tests, and at the same time make a little money out of it. The Institute possessed among its members all sorts and conditions concerned in the making and handling of the non-ferrous metals; it was therefore of the utmost importance to them that they should have that generous display of facts and the free expression of opinion they had been favoured with by Sir Henry that afternoon.

The resolution was then put and carried by acclamation.

The PRESIDENT thanked Dr. Rosenhain and Mr. Seaton for the exceedingly kind way in which they had proposed the vote of thanks, and the members for the cordial manner in which they had received the address. The compliments they had paid to him were, he was afraid, not quite deserved. He would do his best to further the welfare of the Institute, but he asked the members to remember that he could not devote too much time to its work. Luckily the Presidency did not involve very much work in the daytime, and the Institute possessed a splendid Council of keen and energetic men, which made the work of the President very much lighter than it otherwise would be.

The meeting was adjourned at 5 P.M. until 10.30 A.M. the following morning, Wednesday, March 18, 1914.

SECOND DAY'S PROCEEDINGS.

WEDNESDAY, *March* 18, 1914.

At the adjourned meeting, which was presided over by the President (Engineer Vice-Admiral Sir H. J. Oram, K.C.B., F.R.S.), papers were read by Mr. J. Dewrance (London); Messrs. R. J. Dunn, M.Sc. (Manchester), and O. F. Hudson, M.Sc. (Birmingham); Professor A. A. Read, M.Met., and Mr. R. H. Greaves, M.Sc. (Cardiff); Messrs. J. E. Stead, D.Sc., D.Met., F.R.S., and H. G. A. Stedman (Middlesbrough), and Messrs. S. Whyte, B.Sc., and C. H. Desch, Ph.D., D.Sc. (Glasgow). First Reports to the Beilby Prize Committee and the Nomenclature Committee were presented by Messrs. C. H. Desch, Ph.D., D.Sc. (Glasgow), and W. Rosenhain, D.Sc., F.R.S. (Teddington), respectively. The paper by Mr. G. H. Gulliver, B.Sc. (Edinburgh), was taken as read.

Each paper and report, except that of Mr. Gulliver, was followed by a discussion, a hearty vote of thanks being accorded in each case, on the motion of the Chairman, to the respective authors.

CONCLUDING BUSINESS.

The PRESIDENT said that his next duty was to propose a vote of thanks to the Institution of Mechanical Engineers for the use of the hall in which they had been meeting, and the rooms in connection therewith. He remembered quite well, about thirty years ago, when he commenced attending the meetings of the Institution of Naval Architects, which were, as now, held in the rooms of the Royal Society of Arts. It was only after five or six years' annual attendance, and when he became a Member of Council of the Institution of Naval Architects, that he was disabused of the idea that the rooms belonged to the Institution of Naval Architects. He hoped there were no similar mistake being made in the minds of the members of the Institute of Metals in connection with the hall in which they had held the meetings. The Institute was greatly indebted to the Institution of Mechanical Engineers for their great courtesy, and also for the kindness of their officials. He

begged to move : " That the best thanks of the Institute be, and are hereby tendered to the Council of the Institution of Mechanical Engineers for their courtesy in permitting the use of their rooms on the occasion of this meeting."

Mr. A. PHILIP seconded the motion, which was carried with acclamation.

Dr. J. E. STEAD, F.R.S., then proposed a most hearty vote of thanks to the President, Sir Henry Oram. Sir Henry had conducted the meetings with ability, geniality, and efficiency. Because of his high position the members welcomed him as their President ; not only that, but Sir Henry possessed great practical experience, and also had induced a great many of his friends to join the Institute. The resolution was : " That a hearty vote of thanks be given to the President for his able conduct in the chair."

Mr. C. BILLINGTON seconded the motion, which was carried with acclamation.

The PRESIDENT briefly replied, and at 5.30 P.M. the meeting terminated.

PRESIDENTIAL ADDRESS.*

By Sir HENRY J. ORAM, K.C.B., F.R.S.
(Engineer-in-Chief of the Fleet).

I DESIRE to thank the members of the Institute of Metals sincerely for electing me to the position of President of the Institute, and to acknowledge their action in doing so as a compliment to that great branch of the public service—His Majesty's Navy—to which I have the honour to belong.

The objects aimed at in the formation of the Institute of Metals and the circumstances connected with its early history have been exhaustively dealt with by the late Sir William White and by Sir Gerard Muntz in their Presidential Addresses, while the relations of the Institute with other similar bodies, and its duties to the public, have been recorded by our retiring President, Professor Huntington. There is nothing new to be said on these subjects, and I shall therefore not further touch on them.

The activities of the Institute during the past year are concisely set forth in the Report of Council, which has been read by the Secretary, and this shows that the past year has been a very busy one for the Institute of Metals, with much good work done and progress made.

One paragraph in the Council's report to which I desire to make some reference is that which records the death of my friend and colleague of so many years—Sir William White, our first President. Although Sir William had been associated as President with practically all the engineering and allied technical associations, his connection with the Institute of Metals was close and special. He was one of its most active founders, and we shall always be grateful for the great interest he evinced, and the amount of work he undertook, in furthering the welfare of this Institute at its inception. He had also the distinction of being our first Fellow, and everyone who knew his capacity must regret that his membership,

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* Delivered at Annual General Meeting, London, March 17, 1914.

which would have been of such great value to the Institute, has so quickly ended.

The Hon. Treasurer's report deals clearly with the finance of the Institute. Our financial position is quite sound, but requires the accession of many new members to enable the Council to authorize that financial expenditure in various directions which is an essential adjunct of research and enterprise. What has already been done indicates that the result of such further expenditure would benefit our members and add to the general credit and usefulness of the Institute, and it is hoped that the growth of membership in the near future will permit such desirable advances.

We are fortunate in possessing a treasurer who is indefatigable in our interests, and under whose guidance we shall not drift into a weak financial position. We are under no small obligation to Professor Turner, one of our Vice-Presidents, for the work he has done as Honorary Treasurer since the formation of the Institute.

The papers presented during last session and to be read during our present meeting are of a very useful character, and are in my opinion well worthy of the Institute. Our Summer Meeting at Ghent was particularly successful in this respect, a considerable number of excellent papers being read, while the social and holiday side of the meeting was probably considered by some to have been even more successful.

Our Journal is a great success. In addition to its valuable contents, it is convenient in size, and the great demand there is for the volumes, independently of those issued to members, shows that their contents are highly appreciated. I believe that we may fairly claim that our Journal, with its papers and valuable abstracts, is worthy of the important industries which the Institute has in its care.

This Institute, as is well known, was founded in 1908, the number of members at the end of its first year being 355. There has been a steady increase in membership, which at the end of 1913 was 626, and if all those are elected whose names appear in our present list the number will be 640.

Although there has been a continuous increase in membership from the beginning, there are welcome indications at the

present time that the usefulness of the Institute is being more fully recognized, especially by the engineering profession, and more particularly marine engineers and shipbuilders. I hope that before long the Institute will receive a considerable access of membership from these sources, which will assist it in combining the work of research with the commercial requirements of the manufacturer and the needs of the designer and user, or in other words the co-operation of theory and practice in obtaining the best possible results.

With the limitations constantly being imposed on the marine-engine designer, especially when dealing with warships, in regard to weight, space, and first cost, and the obvious necessity of obtaining great durability and reducing the cost of upkeep, marine engineers and shipbuilders are aware, perhaps more than the members of any other of the allied branches of engineering, how difficult it is practically to obtain the ideal conditions which laboratory experiments indicate to be desirable, so that more frequent discussion by them of their view of the problems dealt with at the meetings of the Institute would, I am sure, be of great value to us all.

I feel somewhat guilty in accepting the presidency of the Institute of Metals, seeing that I am often busily engaged in endeavouring to dispense with non-ferrous metals in warships' machinery in cases where experience shows, as it often does, that the qualities of ferrous metals are more suitable.

New warship machinery of to-day is greatly different in this respect from that of some years ago, and when these newer ships come into the ship-breakers' hands many years hence, there will not be found that wealth of copper, brass, gun-metal, &c., which used to be common in the machinery, and which added so largely to the scrap value of the older ships.

It will be interesting to note the records showing the amount of copper, brass, gun-metal, and other non-ferrous metal work that a modern warship contains in her structure, that is, the hull, machinery, guns and mountings, as compared with the amount of steel and iron.

Although the non-ferrous metals cannot usually compare with steel in structural strength, there are still many positions

in which other qualities than strength are necessary, and these metals are still indispensable. Approximately every 100 tons of iron and steel used in modern warships requires to be supplemented by 6 tons of copper or its alloys in a battleship, or 8 tons in a cruiser, to give the completed war-ship her final and necessary qualities. The increase in the non-ferrous requirements of the cruiser is due to the smaller proportionate amount of armour, and the higher power of the machinery, which latter contains a larger proportionate amount of non-ferrous metals than the remainder of the structure.

The propelling machinery in the modern battleship referred to above contains a weight of non-ferrous metals equal to 17 per cent. of that of the contained steel and iron. If we go back twenty years and consider a battleship of that period, we find that the non-ferrous metals in the propelling machinery amounted to about 34 per cent. of the steel and iron, or just double the percentage at present obtaining.

In the hull structure, excluding the propelling machinery, the proportionate amount of non-ferrous metals has, however, not been reduced as compared with twenty years ago. Although steel has taken the place of copper and its alloys to a large extent, this reduction has been counterbalanced by the considerable increase in gun turrets and their machinery, fire control appliances, electric lighting, telephones, &c., where non-ferrous metals are requisite. Considering the hull structure alone, excluding propelling machinery, the figures for the modern battleship referred to are that the non-ferrous metals amount to 4·4 per cent. of the iron and steel, while for the battleship of twenty years ago the proportion was 4·2 per cent., thus showing a slight increase in non-ferrous metals.

Except for the very smallest pipes, copper steam pipes have not been used in new ships for many years, and one recalls the feeling of relief at the Admiralty when the last copper steam pipes containing high-pressure steam had been safely " wired " or replaced by steel before further loss of life occurred.

Gun-metal ends for condensers have also disappeared, and been succeeded by cast iron, to the great advantage of the condenser tubes, and the condenser shells have now also for

some years been made of sheet steel, which is lighter, and, although not so durable as gun-metal, is sufficiently so having regard to the probable life of the ship. Feed discharge pipes and fire service pipes, made of copper for so many years, are also now made of steel.

Although, however, in the directions indicated the non-ferrous metals are giving place to steel in warships, the application of these metals in some other directions is steadily increasing, so that there is no material reduction in the area of usefulness which exists for non-ferrous metals, and in this area the need for further accurate knowledge and experiments to enable these metals to reliably fulfil the purpose for which they are fitted is perhaps greater than ever. It is the object of the Institute of Metals to develop and foster such experiments and to increase such knowledge, and I am sure the Institute will not be found lacking in this duty. There is still a field of usefulness for non-ferrous metals not yet closed, owing to the inability of makers to produce satisfactory steel castings. Complicated machinery castings are no doubt difficult to produce in steel, but whatever the reason may be, the delay and occasionally even the impossibility of at present obtaining them in cast steel have obliged the Admiralty to rely more largely on gun-metal for certain parts than the merits of that material appear to warrant.

In the event of a cast steel valve-box being found defective there is often no option at present except to replace it in gun-metal, otherwise we should have warships delayed in delivery, or withdrawn from active service, for an undesirable period.

This being so it is unfortunate that gun-metal loses at high temperature so much of its strength and powers of elongation under stress before fracture, but we may console ourselves with the knowledge that under a steady load a large amount of elongation is not really essential, although desirable, and there is the fact that in the British Fleet there are thousands of gun-metal valves which have been working at high temperatures and pressures for years, in which there have been no failures due to brittleness or loss of strength at high temperatures.

What exactly occurs with gun-metal at high temperatures is at present not sufficiently established. In the last two or three years three different and quite independent experiments on this subject, carried out by competent workers, have come under Admiralty notice, which differed considerably in the results obtained both as regards the loss of ultimate strength and elongation before fracture.

One must conclude that considerations, such as the temperature of pouring, the exact method of mixture, the time the specimen is allowed to be under the influence of the heat, and other factors, bulk much more largely in influencing the results of such experiments than is usually admitted, and exercise so large an effect on the results as to render them unreliable as a guide to actual practice, unless fully considered and allowed for. The exact effects of temperature and such other influences, knowledge of which would be of much value, seem to require a lengthy and systematic series of experiments, which I believe have not yet been undertaken so thoroughly as the importance of the question warrants.

In connection with this subject, it is the fact that methods in brass foundries are often still of the haphazard and rule of thumb variety, and close supervision by the chemist or other scientist, which is essential to continuous success, is often wanting. Pyrometers, although more largely used than formerly, are still often unknown, temperature being frequently judged by the eye. One finds generally a lack of scientific precision and knowledge in the melting, mixing, and pouring, which, if it existed and were combined with practical experience, would greatly add to the value of an establishment.

It has been stated that engineers are not able or willing to give particulars of their experiences in such a way that they can be used by research workers. I should not care for that view to be accepted unreservedly. In the Royal Navy it is a frequent occurrence for cases of corrosion or other deteriorating action to be reported, the causes of which are obscure or beyond the power of the engineers in charge to discover. In such cases our thoughts at once turn to our laboratory at Portsmouth, and often the engineering reports, although incon-

clusive, are sufficient to enable the more scientific and accurate chemical knowledge of the laboratory to suggest remedial measures for the evil.

Recently also we have had the opportunity of availing ourselves of the resources of the National Physical Laboratory in investigating cases of failure, the causes of which are not clear, and one must acknowledge the value of this admirably conducted establishment in dealing with and reporting on all such investigations as are committed to the charge of its officials.

It has been by such methods, and with the valuable cooperation of the manufacturers, that the Admiralty have dealt with those failures of condenser tubes either by splitting, corrosion, or in other ways, to which I refer in greater detail later. By these means also, the Admiralty have determined the practical tests which have guided manufacturers and introduced methods of treatment and protection in use, which together have practically relieved us from any considerable anxiety in this matter.

This Institute has taken up the question of corrosion of condenser tubes in great detail, having appointed a representative committee to deal with the matter. The second report to this committee by its Investigator, which was presented and read at the Ghent meeting last year, is a most valuable document to those interested in the question, and both directly and indirectly it will well repay the time spent in its perusal and study. The report was of special interest to the Admiralty, as it confirms Admiralty practice and experience of the last twenty to thirty years.

I would like now to call the Institute's attention to, and to emphasize the remarks in, the Report of Council on the top of page 5 as to the necessity of further contributions to the funds of the Corrosion Committee. The work this committee is performing is of great practical utility, and our wealthy friends could not find a worthier channel for contributions and assistance than is provided by the work of this committee.

On examining the last report of this committee, it is of interest to note the good results given by a condenser tube alloy containing 2 per cent. of lead. Hitherto engineers have had a considerable prejudice against lead in the copper-tin-

zinc alloys, and perhaps the prejudice was not very definitely founded, but the satisfactory results given by the alloy referred to above, and those given by a gun-metal alloy containing a small percentage of lead, at high temperature, should cause the prejudice to come under review, and some light appears to be forthcoming on this important matter.

It is possible that the percentage of lead in such alloys must be confined within very narrow limits to give the physical qualities required, and that outside these limits the alloy is unsuitable for the purpose intended.

If this view be correct, and the proper percentage of lead, and the limits of variation from this percentage that can be allowed, can be determined in the case of alloys intended for certain purposes such as for use with high-pressure steam, a great want will have been met. This important subject, the influence of varying proportions of lead in small quantities on the physical qualities of the copper-tin-zinc alloys, might well receive more consideration from the laboratory workers, manufacturers, and engineers of this Institute.

In order that progress may be attained, and an improvement realized in the adaptability of a material to its designed end and practical use in engineering, close co-operation should exist between the scientist and designer, the maker, and the user, and such an institution as this, forming a centre for the free discussion and circulation of opinions, should be of the greatest utility.

The number of papers read before this Institute dealing with the finished product on the practical side and from the user's point of view have been comparatively few, and on this account the remarks respecting condenser tubes which I propose to make may be of interest, for in this case it was only by such mutual co-operation and interchange of ideas that a real advance was obtained as regards increased reliability of these important items of a warship's machinery equipment. There is no part of the machinery of ships on which more thought and time has been bestowed, or which has a more far-reaching effect on the reliability of the machinery than that seemingly simple article—the condenser tube.

Although the corrosion of condenser tubes is a defect of

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serious importance, many of the worst troubles that the
Admiralty have experienced with such tubes have not been
from corrosion or perforation, but from splitting when at work,
which is a far more serious defect.   The number of failures of
tubes due to corrosion and perforation is much in excess of
the number that fail due to splitting, but the more serious
consequences which result from splitting are such as place
these defects in the front rank of undesirable occurrences.

When a tube perforates or corrodes, the hole first made is
minute.   It gradually gets larger with time, but before it
becomes enlarged to any considerable size there are usually
opportunities of detecting the presence of small quantities of
salt in the feed water and boilers, and when such presence is
discovered efforts are made to locate the tube which has
failed, generally with success, so that it can be plugged
temporarily and renewed later at a convenient opportunity.

In the case of a split tube, however, water being in most
cases inside, it is generally the case that the entry of sea water
from the tube into the condensed steam space is considerable,
and may even amount to water pouring into the steam space
full bore, from each end of the tube, so that the amount of
damage usually done in this way by a split tube is far in excess
of that due to a perforated tube.

In the effort to avoid the cause of this defect it will have
to be borne in mind that the tube has to be soft and ductile
so that it will resist any tendency to splitting or flying, but at
the same time it must not be too soft to resist the pressure of
the packing material which is applied at the ends to prevent
leakage.   As these two requirements are necessarily mutually
antagonistic, difficulty is found in uniting them in condenser
tubes.

Condenser tube failures are of the greatest importance to
the Navy owing to their ill effects as regards corrosion of steel
parts, priming, cleanliness of boilers, and in other directions.
In 1899 the number of such failures had become undesirably
important.   They were held to be due to the rise of boiler
pressure and the use of water-tube boilers.   The Fleet were
therefore given orders to report to the Admiralty each case
of failure of a condenser tube either by corrosion, perforation,

splitting, or deformation occurring in ships with 150 lb. boiler pressure or above.

A number of standard questions have to be answered by the ships' officers making their report, including the position of the defective tube in the condenser, the length of time it has been at work, its maker, and other particulars, so that a post-mortem examination is held on each condenser tube which fails. By this means a large mass of information, as complete as can be furnished by sea-going ships, is accumulated; and by gradual deduction from these reports, supplemented by laboratory experiments where indicated to be necessary, and by assistance step by step from the manufacturers, we see the direction in which to work to eliminate those defects which are due to known and remedial causes.

The efforts of the Admiralty to effect a reduction in the number of failures of condenser tubes on service, which have also caused them to consider the question of manufacture and the detailed testing of condenser tubes, have extended over a considerable time. We have not always at first been able to carry the tubemakers with us, and some noteworthy differences of opinion have manifested themselves among the various makers when approached by the Admiralty on apparently simple matters. These differences of opinion seem to indicate the desirability for greater co-operation among the tubemakers themselves and a greater interchange of ideas and experience, by which they themselves would benefit and their customers would also reap advantage.

It is always difficult to convince a manufacturer who has been occupied for many years in making a speciality, such as condenser tubes, and whose plant and methods are ordered and organized, that his products are susceptible of improvements, or that defects occurring on service can be reduced by improvements in the process of manufacture adopted by him. The Admiralty, however, have been successful in enlisting the hearty co-operation of tubemakers generally in this important Naval requirement, and our thanks are due to them for their valuable assistance in arriving at the present comparatively satisfactory condition of affairs.

One of the many orders issued by the Admiralty with the

view of minimizing corrosion in condenser tubes is an instruction to ships' officers to drive the circulating pumps at high speed at frequent intervals to clear tubes of cinders, &c. Although the Second Report to the Corrosion Committee appears to throw doubt on the influence of such matter in starting local corrosion, yet as the Report also points out advantages from the corrosion point of view in keeping low condenser temperatures, and bearing in mind that any obstruction in the tube reduces the flow of water and hence raises the temperature of the tube, the instruction is justified by this further consideration.   In addition, a single line of flow for condensing water is pointed out as beneficial, and all these recommendations are worth bearing in mind and applying as far as practicable ; but where high powers have to be squeezed into the minimum of space, as in warships, we cannot insist on such considerations, and are often thankful to be able to get reliable machinery at all in the space allowed.

At one period the failure of condenser tubes, especially due to splitting, was so frequent and important that it really became a serious menace to the efficiency of the Fleet, and the engineering branch of the Admiralty were naturally much pressed by their Lordships to remove this serious cause of inefficiency ; but a knowledge of the history of condenser tubes in H.M. Fleet at that time, shows that everything practicable had been done according to the information available.   It therefore became necessary for the stringency of the specification to be increased and the inspection by Admiralty overseers to be made more strict to eliminate defective tubes, both during manufacture and after delivery.

As the condenser tube has bulked so largely in the Report of the Institute's Corrosion Committee, I propose now to give a brief account of the development of these tests and conditions during the last twenty-five years, and have referred to a few of the opinions which the tubemakers have been good enough to favour the Admiralty with, this information being given in the hope that it will be of interest to various makers in comparing notes of their competitors' opinions and also of advantage to the Institute generally.   A complete account of the very large number of suggestions and opinions of tube-

makers made in response to Admiralty inquiry would, I feel sure, be of interest and value, but the limits of a Presidential Address will not permit this.

Prior to 1890 the condenser tubes in the Navy were made of the 70-copper, 30-zinc composition, but owing to repeated failures of condenser tubes in the Fleet the Admiralty specification was in that year revised, and the alloy altered by adding 1 per cent. of tin in lieu of 1 per cent. of zinc, the revised composition being 70 per cent. copper, 29 per cent. zinc, 1 per cent. tin.

An effort also was made, even so long ago, to introduce a flattening test, but it was not embodied owing to opposition on the part of the makers, and instead heating and jarring tests were introduced.

In 1891 the quality of the copper used was specified to be not less than 99·3 per cent. pure, while a little later tubes which were too soft were guarded against by a clause specifying that they should be stiff enough to stand the packing being screwed up sufficiently tightly to hold 30 lb. pressure of water.

The specification was next amended so as to require tubes drawn from billets to be accurately bored and turned before being subjected to the final draws. It was found that in making the shells from which tubes were drawn, the bore was frequently eccentric, and often excessively so, and therefore the finished tubes were often thin on one side although the total weight per foot was correct.

The defect of splitting became very common with the development of torpedo-boat destroyer machinery, and in 1900 the tubemakers were asked several questions by the Admiralty, among them being—

1. Whether boring and turning the shells before drawing would facilitate the rejection of those which may produce tubes likely to develop splitting.
2. Whether any alteration of the alloy was considered to be desirable, or whether the splitting might be due to impurities introduced with either of the elements employed.

As regards 1, the replies indicated that some firms thought

that boring might be advantageous, but the general opinion was against both boring and turning.

As regards 2, no alteration of the alloy was suggested, except by one firm who thought 1 per cent. of tin was a disadvantage and that an alloy of 2 copper to 1 zinc would render splitting less frequent; while another represented that splitting must not be attributed to impurities in the metal.

In 1901 some important tests were introduced; among others:

1. A flattening test to one-half the original diameter without previous annealing.
2. Heating to a dull red heat without splitting.
3. Selected tubes to be sawn through and examined for internal defects.
4. The tubes should be drawn on a mandril.

The flattening test proved to be the most important addition, and produced a great stir among the tubemakers when the results became known, and rejections were common.

Representations were made to the Admiralty by the tubemakers concerning the flattening test, with the result that after much consideration a letter was issued to the makers informing them that this test would not be enforced at present, as far as rejection was concerned, but would be continued to be made for Admiralty information.

In acknowledging receipt of this letter, however, one firm stated that they were strongly in favour of this test, "which we consider to be both proper and desirable in order to ensure freedom from splitting when the tubes are in use."

In 1902 the condenser tubemakers were again asked to suggest alterations to the specification with a view to obviating splitting, pitting, &c.

They were asked to remark, among other matters—

1. As regards any alteration proposed in the alloy.
2. On the tests then specified, and with regard to the flattening test then in abeyance, whether a bulging or a flattening test was preferred.
3. Whether they could supply tubes having diameter within narrow gauge limits.

As regards 1, firms either considered the specified alloy

suitable, suggested mercantile marine practice (70 : 30 alloy); or

(*a*) One firm suggested 60 : 39 : 1 alloy, and offered to make tubes of this material, but later withdrew the suggestion. They also suggested 1 to 2 per cent. of manganese in lieu of tin.

(*b*) Others suggested various special tubes, but did not bring any proof that they would be superior to the Admiralty alloy.

As regards 3, the firms stated that they could work to a margin ranging from 0·003 inch to 0·01 inch.

With regard to 2, most firms preferred flattening to bulging, but one firm preferred neither, stating that flattening and bulging tests encouraged the making of tubes of a semi-soft nature and of unequal densities throughout.

The great majority of firms, after a short time, adopted more or less the Admiralty view, the use of electrolytic copper becoming more common and the purest qualities of zinc and tin commercially obtainable being used.

In 1904 there was another revision of the specification, after personal visits to the firms by Admiralty overseers. The following stipulations, amongst others, were introduced :—

1. The amount turned off and bored out of billets for condenser tubes should be sufficient to remove all surface imperfections.

2. The external diameter of the tubes to have a limiting variation of 0·005 inch.

3. The flattening test was reintroduced, $\frac{5}{8}$-inch tubes to be reduced to $\frac{1}{2}$ inch. All tubes to be left 2 inches longer than the required length, so that every tube could be tested.

There was some opposition to these new provisions, the principal difficulty being as regards the boring and turning conditions, which, however, were retained.

A Machinery Designs Committee was at that time in existence at the Admiralty, consisting principally of engineers outside the naval service, and they recommended that the Admiralty should define the extent of the final draw in the manufacture of condenser tubes, and a letter was addressed in 1905 to four of the principal tubemakers asking their

opinion on this matter. At the same time they were also asked their opinion as to the exclusion of "scrap."

In their replies the firms were all in favour of clean "scrap," and gave their list of draws. One expressed the opinion that the material used was far more important than the number of draws, and asked that the original flattening test should be reintroduced (*i.e.* flattening to half the original diameter).

All the firms were again consulted in 1906 as regards the advisability of specifying—

1. The draws of the last but one, and last tubes, together with the dimensions at each stage.
2. The amount bored out of the castings to be not less than $\frac{1}{4}$ inch of diameter. ·
3. The copper used to assay not less than 99·7 per cent. pure.
4. Scrap not exceeding 20 per cent. may be used, providing it is strictly limited to the ends cut from tubes during manufacture.
5. The flattening test to be applied to either end of the tubes and the diameter of $\frac{5}{8}$-inch tubes to be flattened to $\frac{7}{16}$ inch.

The replies of the various firms were as follows :—

Only one firm objected to the limitation of scrap. Three firms objected to the draws specified. Three others were prepared to accept all the tests and requirements. Two others considered the purity of the copper required was too strict, and suggested 99·5 per cent. ; while another considered 99·7 per cent. copper a mistake, as it would involve the use of electrolytic copper, which they deprecated.

One firm objected to the amount bored out ; while another considered $\frac{1}{4}$ inch was too much, and that $\frac{1}{16}$ inch would be sufficient ; and lastly, one objected to turning the castings, but agreed that boring was beneficial, and also agreed with the purity of the copper required and were prepared to agree to the draws specified, but considered that variation of hardness would result.

After considering these replies it was decided not to specify anything concerning the drawing of the tubes, and a specifi-

cation for condenser tubes was issued in 1906, which included the following :—

1. The copper to assay not less than 99·6 per cent.
2. Scrap to be limited to ends removed from process tubes, and not to exceed 20 per cent.
3. Total impurities not to exceed 0·625 per cent.
4. The amount bored out of castings to be not less than $\frac{1}{4}$ inch of diameter.

This revised specification has held good to the present date with the addition that electrolytic copper may be used, and its success, when coupled with some improvements in condenser construction, has well repaid the time devoted to this important matter.

In 1908–9 many cases of split tubes occurred in a new battleship's condensers, and a suggestion was made to the Admiralty that a tensile test should be made instead of a flattening test. As at this time it was desired to take the views of the tubemakers on some other points, this proposal was included in the reference.

The eight principal tubemakers were therefore referred to in 1910, and they were also asked, among other things, whether they would propose any modification in the method of carrying out the specified flattening test.

The replies indicated that three of the firms had no objection to a tensile test if applied to 1 per cent. of the tubes, but all the remainder were strongly in favour of the flattening test being retained, but made various suggestions for making the test with lever presses or drop hammers instead of the hand hammer.

In the words of one firm, "it would be a great mistake to do away with the flattening test, which is an excellent proof of proper alloying." This firm further stated that the present specified impurities allowed, viz. 0·625 per cent., might with advantage be reduced by one half.

From the above it appears that the majority of the firms were in favour of the flattening test, and the Admiralty saw no reason for abandoning it.

It may be asked what has been the practical result of

these efforts on the part of the Admiralty and their tube-
making collaborators.

My opinion is that the most beneficial action taken by
the Admiralty during recent years is the practice adopted
in 1904 by which a test-piece was allowed for on each tube
for the flattening test, a small piece being left on extra to
the proper length, these pieces being sawn almost through
but not detached from the tube, and subsequently removed.

It is impossible to give the number of failures on service
in the Fleet in detail, except in recent years. The earlier
failures were very numerous. The following detailed figures
are available as evidence that they have been reduced to
more satisfactory proportions. In the year 1908, when the
approximate number of condenser tubes at work at sea in
the British Fleet was 2,500,000, the number of failures of
tubes occurring on service and reported were: splitting, 21;
corrosion and perforation, 69; total, 90, or at the rate of 1
in 28,000 per annum.

During the next five years there was a very considerable
addition of new condenser tubes in the ships added to the
Fleet, owing to the great increase in horse-power of modern
ships, also a considerable number of old tubes passed out of
the service. In the year 1913 the number of condenser
tubes at work in the British Fleet was approximately
3,800,000, and the total failures of tubes reported during the
two years 1912 and 1913 were: splitting, 16; corrosion
and perforation, 115; total, 131, or at the rate of 1 in
60,000 per annum—a very substantial reduction.

A further point is that of this proportion of 1 in 60,000,
the majority are probably the older tubes which have been
made under early specifications and which have not had the
present stringent regulations as regards treatment during
manufacture and inspection applied to them. As these
older ships and tubes fall out of service, the proportion of
tubes which fail may be expected to be less even than this
small figure.

The ideal to work for is to reduce the failures to zero,
but beyond a certain point further tests, restrictions, and
additional precautions, both in treatment when at work and

during manufacture, becomes so expensive as to be not worth the cost involved, in which case we must be satisfied with the success already achieved.

In view of the number of failures of condenser tubes caused by corrosion and perforation by salt water where the circulating water passes through the tubes, close attention has been recently given to endeavours to eliminate the causes of these perforations. An incipient cause of some of the cases appears to be the existence of original flaws or breakages of the inside surface of the tube, and to endeavour to eliminate such tubes the Admiralty have recently required a rigid internal examination. The result of this internal sighting has been to indicate defects in the tubes, and such tubes on being cut up have, in a large number of cases, revealed imperfections such as to justify their rejection, and which, if these tubes had been fitted in place, would probably have caused early perforation.

I think I have shown that the Admiralty has endeavoured to combine the observations and experience of the user, and the experimental work of the laboratory, with the commercial possibilities of the manufacturer, with the object, first, of securing reliability in the machinery of warships, reliability being of paramount importance in the time of war; and secondly, of securing that reliability with the minimum of cost.

Similarly, in this Institute, we hope to see the same co-operation and co-ordination of the work of the three main groups of members, in striving for the elucidation of all the problems connected with non-ferrous metals and their working and use. I have devoted some time to the condenser tube, as it has been the subject of special consideration by the Institute, but there is a large field for work for the members in other directions.

In order to obtain the best materials commercially possible to meet the requirements of design, there is a great deal to be ascertained as regards such matters as the obscure cases of corrosion of copper pipes, and of pipes of other non-ferrous alloys; the characteristics and peculiarities of alloys subjected under working conditions to stress under high and

varying temperatures ; the question of suitable alloys for propeller blades, especially with high speeds of revolution ; and in many other directions.

There is, therefore, a large field for research work of obvious practical utility, and as among the various members of this Institute, differing as they do in their methods and thoughts but working towards the same ends, there exists a large body of scientific, experienced, and observant men, their united efforts should aid largely in the solution of such problems, which will be for the general good of the engineering and industrial world.   I hope that our present meeting may bear fruit in this direction.

FIRST REPORT

COMMITTEE ON THE NOMENCLATURE OF ALLOYS.*

A COMMITTEE to consider the whole question of the nomenclature of alloys, as raised in a paper, "A Note on the Nomenclature of Alloys," read by Dr. W. Rosenhain at the annual general meeting of the Institute of Metals, held in London on January 17, 1912, was appointed by resolution of the Council of the Institute of Metals on April 24, 1912. It was decided that the Committee should consist of eight members appointed by the Council as representing the Institute of Metals, and that the councils of allied societies and institutions should be invited to nominate representatives on the Committee. The composition of the Committee as finally appointed is as follows :—

> *Institute of Metals.*—Dr. W. ROSENHAIN, F.R.S. (*Chairman*); G. A. BOEDDICKER, Esq.; Dr. C. H. DESCH; Engineer Rear-Admiral G. G. GOODWIN, R.N.; G. HUGHES, Esq.; Sir GERARD MUNTZ, Bart.; A. E. SEATON, Esq.; and Professor TURNER, M.Sc.
>
> *Institution of Electrical Engineers.*—W. MURRAY MORRISON, Esq.
> *Institution of Mechanical Engineers.*—GEORGE HUGHES, Esq.
> *Institution of Naval Architects.*—Sir W. E. SMITH, C.B.
> *Institution of Engineers and Shipbuilders in Scotland.*—ALEXANDER CLEGHORN, Esq.
> *North-East Coast Institution of Engineers and Shipbuilders.*—The Hon. Sir C. A. PARSONS, K.C.B., F.R.S.
> *Society of Chemical Industry.*—Professor W. R. HODGKINSON, Ph.D., M.A., F.R.S.E.

Some considerable time elapsed before the representation of allied societies on the Committee could be completed, and the fully constituted Committee was not able to hold its first meeting until May 21, 1913. Since then the Committee has

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* Read at Annual General Meeting, London, March 18, 1914.

held four further meetings, and has also carried on its work by correspondence. As a result of these labours the Committee are now in a position to present a first report, embodying their first series of recommendations on the subject of the nomenclature of alloys.

The Committee at the outset have fully recognized the difficulty of the task which they were approaching, but they have felt no doubt as to the desirability or even the necessity of reform in regard to the naming of alloys. The Committee wish particularly to emphasize that they have not approached this matter in any academic spirit, but have endeavoured to bear in mind in the first place the needs of industry and commerce. Had they merely wished to draw up a system of nomenclature for the use of scientific men their task would have been much easier, since practical and commercial considerations are responsible for the more serious difficulties to be overcome in this matter.

The Committee further fully recognize that they do not possess any power of enforcing the use of the system of nomenclature which they desire to recommend ; on the other hand, existing practice is so confusing that the majority of alloy names as now used possess no rational meaning whatever, and the resulting confusion has led to disputes, and even to litigation. In these circumstances the Committee feel that a rational system of naming alloys will naturally commend itself both to practical men and to teachers and investigators, so that ultimately such a system will find wide adoption, and may, as a matter of usage, backed by the formal support of the representatives of the leading technical societies of Great Britain, attain even to a legal status. The Committee are thus fully alive not only to the difficulty of their task, but also to the responsibility which attaches to their work.

The Committee have from time to time received a very large number of suggestions, both from their own members and from outside, as to the method to be pursued in arriving at a rational system of names for alloys. It would unduly lengthen this report either to enumerate or to discuss these proposals. Careful consideration of all such suggestions has, however, led the Committee to adopt certain guiding principles

in the conduct of their work. These may be briefly stated as follows :—

(1) So far as names intended for use in industrial and commercial practice are concerned, it is desirable to adhere to existing names sanctioned by long usage as far as possible, provided that all such names can be so defined as to avoid all risk of confusion or ambiguity.

(2) The coining of new names or the adoption of recently coined names not in general use should be avoided as far as possible.

(3) It is desirable to employ simple English names throughout, avoiding the use of Latin or foreign names, and of chemical or other symbols.

These principles require little explanation, but in regard to (1) the Committee desire to point out that in view of the admitted existence of confusion and ambiguity in the case of many names in current use, the ultimate abandonment or modification of *some* existing terms is unavoidable if the present state of affairs is to be improved. It is not suggested, however, that any sudden change which might prove disturbing to commercial relations should be made. If the new or modified terms indicated in the present and in future reports of the Committee are adopted by writers and teachers who deal with alloys, their use will gradually permeate all ranks of those concerned with metals, so that the necessary change will be a gradual and natural one, and all sudden disturbance will be avoided.

From the principles laid down above it follows that the task before the Committee resolved itself into that of framing rational definitions of the more widely used alloy names. In order to accomplish this in a satisfactory manner the committee have found it desirable to establish in the first place a rational or systematic nomenclature based upon some completely general principle. Such a system of nomenclature would probably be too cumbersome for general use, and would depart too widely from ordinary usage to be satisfactorily employed for industrial or business purposes. Its main object,

apart from possible use by scientific writers, is to serve as a basis for the definition of what may be called "practical names." The Committee have, in fact, aimed at defining practical terms as simple abbreviations of the systematic names of alloys.

After much discussion the Committee arrived at the decision that the only principle of sufficiently wide applicability upon which they could base a rational or systematic nomenclature was that of naming alloys according to their chemical composition by weight. Although there are cases of some difficulty even under this principle, the fact remains that every alloy possesses a definite and definitely ascertainable composition by weight, and that—speaking in the most general terms—the properties of alloys are more universally dependent upon their chemical composition than upon any other single factor of general importance.

The principle which the Committee has adopted for the construction of a system of nomenclature on the basis just indicated is that of denoting any alloy by the names, in English, of its component metals, placed in the order of increasing numerical importance from the point of view of chemical composition by weight. In adopting this order for the names of the component metals, the Committee have endeavoured to follow existing usage as closely as possible, although existing practice in this respect is not uniform. Thus "phosphor-copper" follows the order adopted by the Committee, while "cupro-nickel" does not. As examples of what is implied by the principle adopted for the construction of systematic names for alloys, a few instances may be useful, in which the approximate composition of some typical alloys is stated, together with the corresponding "systematic" name.

Composition of Alloy.	*Systematic Name.*
Zinc, 30 per cent.; copper, 70 per cent.	Zinc-copper.
Tin, 10 per cent.; copper, 90 per cent.	Tin-copper.
Tin, 1 per cent.; zinc, 29 per cent.; copper, 70 per cent. .	Tin-zinc-copper.
Aluminium, 8 per cent.; copper, 92 per cent. . . .	Aluminium-copper.
Copper, 3 per cent.; aluminium, 97 per cent. . . .	Copper-aluminium.
Tin, 32 per cent.; lead, 68 per cent.	Tin-lead.

It will be seen that although this system is perfectly simple and rational, this simplicity is accompanied by a considerable

degree of cumbrousness when alloys of more than three metals are to be described. A difficulty also arises with regard to the question of impurities present in notable amount, and another obstacle is found in the case of alloys in which two or more metals are present in practically equal proportions. The Committee have considered these difficulties, and propose the following methods of dealing with them :—

(1) Where an alloy consists of more than three metals its systematic name shall not as a rule contain more than the names of those three metals present in the largest proportion by weight, but the presence of additional metals or elements shall be denoted by the prefix " comp." or " complex." If, however, an alloy of this kind contains an intentionally added element which, although present in small quantity, gives the alloy a distinctive character, that element may be named first. To take an imaginary example: if an alloy containing aluminium 75 per cent., tin 15 per cent., arsenic 4 per cent., cobalt 3 per cent., iron 2·75 per cent., and (say) indium 0·25 per cent., owed its (supposed) special qualities to the presence of the last-named element, it would be denoted as " indium complex tin-aluminium." This is obviously an imaginary case of a very extreme type, and is given merely to illustrate the principle. The resulting name is still decidedly cumbersome, but not too much so for the purposes of a systematic nomenclature which is not intended for general practical use.

(2) As regards impurities present in notable quantities, the Committee have reached the conclusion that since the question of drawing up specifications for the proper composition of alloys lies outside their province, and is moreover governed by entirely different considerations and conditions, the present Committee cannot lay down any rules as to the quantities of " impurities " which may be admitted without reference in the name of the alloy. When standard specifications are available this point will be automati-

cally decided. Meanwhile the Committee recommend that in the systematic names as here defined reference should be made to all elements whose presence in the alloys in notable quantities is *intentional*.

(3) With regard to alloys which contain two or more metals in equal or nearly equal quantities, the Committee recommends that the principle should be followed that where no numerical preponderance is established the metals should be placed in alphabetical order.

Having thus established what they believe to be as simple and rational a system of names as any that could be devised in the circumstances, the Committee have approached the task of defining, in terms of the systematic or rational names, the ordinary names of alloys intended for everyday usage. The principle which the Committee have adopted is that of defining a few of the best known and most widely used terms simply as definite abbreviations or contractions for certain names or groups of names in the systematic nomenclature.

The Committee having in the first instance confined their attention to the alloys of copper, the terms first defined on this basis are " brass " and " bronze." The definitions recommended and adopted by the Committee are as follows :—

Brass.

The term " brass " is to be used as an abbreviation of the words " zinc-copper " as employed in the systematic nomenclature. Thus when the word " brass " alone is employed it shall denote an alloy of zinc and copper only, containing more copper than zinc, *i.e.* containing over 50 per cent. of copper. When an alloy containing a third metal, such as tin, is to be denoted, the name of the additional element shall be used as a prefix, precisely as in the systematic nomenclature. Thus an alloy containing tin 1 per cent., zinc 29 per cent., and copper 70 per cent., would be called " tin-brass." If additional metals are present their names may also be prefixed, or the general prefix " comp." or " complex " may be used if it is not essential to mention the other elements specifically.

Bronze.

The term "bronze" is to be used as an abbreviation of the words "tin-copper" as employed in the systematic nomenclature. Thus when the word "bronze" alone is employed it shall denote an alloy of tin and copper only, containing more copper than tin, *i.e.* containing more than 50 per cent. of copper. The presence of one or more additional metals shall be denoted in the same manner as has been indicated above in the case of "brass."

The Committee is not prepared at the present stage of its work to recommend definitions of any further practical terms, as further consideration is required for the framing of definitions relating to smaller and more strictly limited classes of alloys. But although the Committee thus only put forward definitions for two practical alloy names, yet those two represent by far the most widely used alloys, and the general adoption of the terms as thus defined would in itself do much to remedy the state of confusion which exists at the present time. The Committee therefore express the hope that all those interested in the progress of the industries and sciences connected with metals will use their best endeavours to support the work of the Committee.

Having laid down in the present report the principles upon which a systematic nomenclature of alloys can be established, and the method by which practical names can be defined in terms of that systematic nomenclature, the Committee hope that in their next report they may be in a position to put forward a considerable number of "practical" names.

(Signed)   WALTER ROSENHAIN, *Chairman.*

G. A. BOEDDICKER,
ALEX. CLEGHORN,
CECIL H. DESCH,
G. G. GOODWIN,
W. R. E. HODGKINSON,
GEORGE HUGHES,
W. MURRAY MORRISON,
GERARD A. MUNTZ,
CHARLES A. PARSONS,
A. E. SEATON,
W. E. SMITH,
THOMAS TURNER,

} *Members of Committee.*

DISCUSSION.

Sir Henry J. Oram, K.C.B., F.R.S. (President), said that there was no doubt that the subject dealt with was of vast importance. In his (the President's) opinion there would be a general agreement with the work of the Committee so far as it had gone, but there would be many difficulties to be overcome in the future. If the Committee, in addition to formulating recommendations, could induce all the people who used alloys to adopt the recommendations contained in the Report, they would certainly render a great service to the country.

Dr. J. E. Stead, F.R.S. (Middlesbrough), said that as one who had been often asked to define alloys, especially of a non-ferrous character, he would be very pleased to accept the findings of the Committee, whatever they might be, whether ideal or otherwise. Uniformity was the thing to aim at. He hoped that all members would be loyal to the findings of the Committee.

Mr. T. A. Bayliss (Member of Council) said that one way of making the work of the Committee of more value, and getting it adopted, would be for the Institute to call the attention of every manufacturer to the Nomenclature Committee, and to ask that when quoting for any type of brass or bronze they also should specify the " Systematic Name."

He ventured to think that if the Institute adopted his suggestion the work of the Committee would be prominently brought before the manufacturers of the country, and it would also advertise the Institute.

As a manufacturer himself, he would at once follow the recommendation of the Committee in every quotation made by his company.

Mr. H. H. A. Greer (Glasgow) spoke as one who was a buyer and seller of old metals. He supposed that the intention of the Committee was to develop the commercial side of the question, and he was wondering whether it would not be possible for them to subdivide the word " bronze " and " brass " into " special bronze," " medium bronze," and " common bronze "; and " special brass," " medium brass," and " common brass." The nomenclature of brass and bronze at present was very indefinite. Scotland had an additional term of " Bush brass," which was really a mongrel metal in between brass and bronze. In America that same material was called "composition metal," and sometimes it suited American buyers and American sellers to decide what was "composition metal " and what was not " composition metal." If it suited them to reject the material on account of market conditions or otherwise, they would say it was not " composition metal," but brass. Therefore if the Committee could subdivide the terms " bronze " and " brass " into the three classes he had mentioned, it would, from the commercial side of the question, be of extreme value.

Mr. E. J. Bolton (Stoke-on-Trent) considered, as a manufacturer, that it was an excellent plan to adopt some definite nomenclature for alloys.

It would be a good thing if people got into the habit of specifying what they required in percentages of copper and zinc and abolished the present terms of "best brass" or "red brass," and so on. The difficulty was that certain manufacturers had special alloys of bronze, for instance, what they called by fancy names. They were under the impression that by so calling them they were able to sell them better. He was quite certain, however, that it would be to the advantage of engineers and users in general if, when buying alloys, they asked manufacturers to quote for a certain percentage of copper and zinc. If they did so there would be uniformity throughout the whole trade. As long as manufacturers gave fancy names to different alloys there was bound to be confusion, and people really not knowing what they were getting. As a manufacturer he heartily approved of the Committee's Report, and would like to see it universally adopted throughout the trade.

Sir WILLIAM SMITH, C.B. (Member of Council), said that he considered that the remarks during the discussion fully illustrated the kind of difficulties to which Dr. Rosenhain had referred. It was, as the last speaker had said, for contract purposes a matter of the utmost necessity that there should be clearness and great precision in the agreement made between the purchaser and the manufacturer. He was not very familiar with the practice of large mercantile concerns, but he had been very closely connected with the practice of the Admiralty over a long period of years. The Admiralty did not use colloquial names other than such old established terms as "gun-metal," and they did not use even that term without specifying the limits of chemical composition within which the manufactured article had to lie. In addition to that they specified certain mechanical qualities which the alloy had to possess.

As an instance of the difficulties which sometimes arose out of the absence of precision, he remembered a case which occurred at the Admiralty many years ago. A contract was drawn up rather loosely, and the material specified was to be gun-metal "of the usual Admiralty quality." The man who drew up the specification thought that gun-metal "of the usual Admiralty quality" was a gun-metal, the composition of which was perfectly well known—and he (the speaker) thought that was the case. It so happened, however, that the manufacturer had seen previously in the newspapers that the Government were going to sell some old guns at Woolwich Arsenal. He therefore went down, bought the old guns, and from these guns manufactured the articles to be purchased. The Admiralty found out that the articles were not made of gun-metal of the usual Admiralty quality. The manufacturer, however, contended that he was perfectly justified in calling the substance "gun-metal of Government quality," inasmuch as it was metal used by the Government in making guns. That case illustrated the necessity in all contract matters of uniformity and precision of terms, and the further necessity, referred to by the last speaker, of specifying in important contracts what the limits of percentage composition should be. Of course it happened that on some occasions the buyer had to go beyond that, and specify the mechanical qualities desired.

Mr. CHARLES BILLINGTON (Longport) said that the question of nomenclature of alloys, such as suggested by the Committee, was a very awkward question when looked at from the manufacturer's point of view, especially when it was considered that some people objected to certain elements being present in an alloy which were essential for the specific purpose required. For instance, a manufacturer had been asked to produce an alloy to give particular results, and he (Mr. Billington) had known such alloys condemned when the composition was stated before the casting was put to use, although afterwards, surprise had been expressed that such an alloy would give satisfaction. It was quite different when dealing with iron and steel, where the alloys were simple and engineers had had more experience of their nature and use than they had of the more complex alloys of the copper and tin series. It would be cumbersome to name a complex alloy containing five, six, or seven essential elements in the manner suggested by the Committee, and to have the word "complex" inserted would not elucidate the matter but cause confusion. Personally, he thought difficulties would arise unless the Committee could suggest names for alloys containing various metals. He quite agreed with many of the suggestions in the Report. His firm had named many of their alloys on the lines indicated, but he thought that it would be a pity to discard the use of the word "gun-metal," as it has been a household word for several generations for an alloy containing copper, tin, and zinc, in contrast to bronze containing only copper and tin.

Professor TURNER, M.Sc. (Vice-President and Honorary Treasurer), mentioned that there had been a meeting of the Birmingham section some few weeks previously at which the proposals contained in the Report were outlined. There was present at the meeting a fairly representative gathering of men, connected with the local trades, who were given every opportunity of expressing their views as to the proposals which the Committee had then drafted, and he (Professor Turner) thought he might say that those suggestions met with practically unanimous approval. Other suggestions were made as the result of that meeting, which the Committee would be able to consider in the future. From that fact he had mentioned, and taking into account the trend of the discussion that morning, it did seem to him that it could be considered that the work of the Committee so far as it had gone—although, of course, it was only preparatory—had been on right lines; and it only remained for members of the Institute to adopt as far as possible the conclusions upon which there was agreement. He referred not only to manufacturers, but to students and teachers, who should as far as possible endeavour to adopt the system of nomenclature put forward in the Report, so that it might become more generally adopted.

Sir HENRY J. ORAM, K.C.B., F.R.S. (President), thought that the general tenor of the discussion seemed to indicate that there would be some difficulty in meeting the views of all the various members of the Institute on this very difficult question of nomenclature. As far as the Admiralty were concerned, there was no doubt that they would do all

they could to adopt the recommendations of the Committee and specify certain existing materials under their new names, thus helping the work of the Committee and assisting in familiarizing the country with them. Mr. Billington had pointed out some difficulties which would arise in meeting the views of certain manufacturers, and that illustrated the obstacles he (the President) anticipated which would have to be overcome in the further work of the Committee. He felt quite certain, however, that the Committee, as constituted, was a very representative one, and would be able to devise some scheme by which the views of the various manufacturers of bronzes and other alloys would be met, at least in a sufficiently satisfactory manner.

Dr. Rosenhain, in replying to the discussion, thanked the members on behalf of his colleagues and himself for their very kind reception of the Report. The Committee were particularly gratified to have promises of support from a number of members whose influential position would go far towards securing the widespread adoption of the recommendations of the Committee. Dr. Stead, Mr. Bayliss, Sir Henry Oram, Mr. Bolton, and other gentlemen who spoke in support of the work of the Committee, had already contributed a very important element towards the practical adoption of the recommendations ; and what really counted in such matters was a lead in the right direction. Of course there were many further difficulties to be faced. The work of the Committee had only just commenced, and what Mr. Greer had suggested was really the next step which the Committee had in mind. "Brass" and "bronze," as now defined, were fairly wide terms, and in a great many cases it was very desirable to limit those terms. The terms suggested by Mr. Greer did not quite appeal to him as being practical. From what he knew of manufacturers and merchants generally, he did not think they would care to call their material "common brass." The difficulty about any name of that kind, however, was that the Committee had to avoid any name which in itself suggested a quality ; all names must be simply and purely descriptive. That was one of the conditions which he thought would have to be followed. Mr. Bolton had referred to fancy names ; the Committee did not propose to define these at all ; if the nomenclature suggested in the Report was adopted, he considered it would lead to the dropping of fancy names to a very large extent, very much to the benefit, he felt sure, of the industry as a whole, and particularly of the users of metals. The Committee had a difficult case to deal with in the matter referred to by Mr. Billington, as it was by no means easy to understand the position. Surely Mr. Billington did not believe that he could introduce a metal into an alloy without the engineer knowing it, if the engineer really wanted to know? It was perfectly easy to analyse a metal and ascertain whether a certain substance was present or not. There might be difficulties in special cases, but personally he had not come across them so far. Therefore he thought that Mr. Billington's was a difficulty which would have to be fought out between the maker and the engineer. If a stupid engineer was not prepared to try a new alloy, it was largely that engineer's loss. On the other hand, if there was a

maker who insisted upon inserting an element which did not produce the effect he imagined, that maker would have to find out and know better in the future. He (Dr. Rosenhain) did not think that this was essentially a matter of nomenclature. All he could say was that the further work of the Committee was likely to be more difficult even than the work it had already performed, and the Committee would be extremely glad to receive as many suggestions as possible. They were particularly grateful to Mr. Bayliss for his suggestion that they should inform manufacturers generally what the Committee was doing and make certain suggestions to them as to how they could avail themselves of the recommendations of the Committee. He felt sure when the Committee next met they would take steps to carry out that suggestion.

In conclusion, he desired, on behalf of his colleagues and himself, to thank the members for the very encouraging and promising reception which they had given to the Report, and for their kind vote of thanks.

COMMUNICATIONS.

Mr. H. H. A. GREER (Glasgow), in reference to the remarks which he made at the meeting, wrote that he did not wish the Committee to think that he was not in entire sympathy with the steps which were being taken for the standardizing of the names of metals, but quite the reverse. The suggestions he made and the names he gave for the different grades of brass and bronze were nothing more than suggestions to subdivide these two classes of metals. The railway companies at present almost invariably, when asking prices for their borings and scrap metals, called them brass axleboxes, brass fittings, brass borings, &c. These were often bronze, and it might be well to ask the railway companies to co-operate also for improvement in this respect. Further, as an example, under classification, how would a metal containing 74·5 per cent. copper, 5·5 per cent. tin, 10 per cent. zinc, and 10 per cent. lead, be treated? Was that a brass or a bronze? It appeared like a very "common" bronze, but a great many castings made for the mercantile marine were not of much better metal.

Dr. ROSENHAIN, in reply to Mr. Greer, wrote that he quite understood Mr. Greer's attitude, and was glad to receive suggestions, not only of possible names, but also of difficulties which had to be encountered and overcome. Mr. Greer's suggestion of the railway companies was a very good one, and at an early stage of the further work of the Committee efforts to secure the co-operation both of manufacturers, as suggested by Mr. Bayliss, and of users, including the railway companies, would be made. With regard to the alloy cited by Mr. Greer as a difficult one to classify, he thought that it could be quite easily classified under the definitions given in the Report, namely, as a "lead-tin-brass," owing to the fact that it contained more brass than any other alloying element except lead, and that lead comes alphabetically before zinc; for that reason its systematic name would be tin-lead-zinc-copper, and the words "zinc-copper" would be contracted into "brass."

FIRST REPORT *

BEILBY PRIZE COMMITTEE OF THE INSTITUTE OF METALS

THE SOLIDIFICATION OF METALS FROM THE LIQUID STATE.

By CECIL H. DESCH, D.Sc., Ph.D.

(Graham Young Lecturer in Metallurgical Chemistry in the University of Glasgow).

THE present investigation is the outcome of a suggestion made by Dr. G. T. Beilby in the May lecture of this Institute for 1911,† and more fully particularized by him in a paper communicated at the Autumn meeting of the Institute in 1912.‡ According to a hypothesis first proposed by Professor G. Quincke,§ the first step in the process of crystallization is the separation of the liquid into two immiscible liquid phases, one of which is formed in relatively very small quantity. This "oily" liquid arranges itself in a manner frequently observed in immiscible oils and aqueous solutions, to form the walls of "foam-cells" (*Schaumkammern*) filled with the liquid which is present in greater quantity. The arrangement of the crystalline particles when actual solidification takes place is then determined by the presence, dimensions, and form of the foam-cells.

In his second paper, Dr. Beilby stated that it was not intended that the inquiry should be restricted to an attempt to prove or disprove this hypothesis, but that it should embrace the general subject of the earlier steps in crystal-

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* Presented at Annual General Meeting, London, March 18, 1914.

† *Journal of the Institute of Metals*, No. 2, 1911, vol. vi. p. 16.

‡ *Ibid.*, No. 2, 1912, vol. viii. p. 186.

§ Detailed references to Quincke's papers are given later. The application of the hypothesis to Metals has been summarized in *Internationale Zeitschrift für Metallographie*, 1913, vol. iv. pp. 23, 79, 303.

lization, both from the liquid and from the solid state, together with the practical aspects of the question in relation to foundry practice.

Following a precedent set by the reports to the Corrosion Committee of this Institute, a first report is now presented, summarizing briefly the present extent of our knowledge on a part of this subject, and giving references to the original publications. The bibliography is not exhaustive, but the attempt has been made to include, as far as possible, the more important original contributions to the study of crystallization from this point of view. Considerable difficulty has been experienced in searching the literature for relevant memoirs, as these are scattered through chemical, metallurgical, geological, and physical publications, and important facts are sometimes to be found in memoirs, the titles of which would not lead the searcher to suspect their contents. In all cases, the original publication has been consulted, in order to avoid the errors which easily arise from quotation at second-hand.

The subject of the formation of crystalline aggregates, such as present themselves in metals, receives little attention in text-books of crystallography. The geometrical study of crystals, and the theory of the possible modes of regular partitioning of space, by means of which the symmetry of crystal classes has been accounted for, have been brought to a very high degree of perfection, and other aspects of the subject have been neglected in comparison. The most perfect crystals are of the greatest value to the crystallographer, and the unequal development of different faces receives only a general treatment from the geometrical point of view, although much interesting work has been published in recent years dealing with the influence of the conditions of growth on crystalline habit.* Such researches, however, refer mainly to comparatively small deviations from the normal form, and distorted, branched, and dendritic forms, which present themselves so frequently in metals, have hardly been examined from the point of view of the crystallo-

* See, for example, P. Gaubert, *Recherches récentes sur le facies des cristaux*, Paris, 1911.

grapher. The best modern text-book of crystallography does not mention the words " crystallite " or " crystal skeleton."

A large number of investigations of a qualitative character, dealing with such structures, is, however, in existence, but has not been taken into account in the compilation of works of reference. An exception should be made in respect of the works of Professor O. Lehmann,* which are an almost inexhaustible storehouse of information relating to the internal structure of bodies.

The mechanism of the process of solidification in relation to the resulting structure has also attracted the attention of numerous recent workers in petrography, in the course of studies of the formation of igneous rocks. From a physico-chemical point of view, the solidification of metals and alloys is essentially similar to that of igneous rocks, the differences in the resulting structures being sufficiently accounted for by the much greater viscosity of the latter, and possibly also by the smaller power of orientation at high temperatures possessed by silicates in comparison with metals.

The present summary is divided into the following sections :—

1. The cellular structure of metals.
2. Crystallization from centres and the formation of crystallites or crystal skeletons.
3. Foam-structures and Quincke's hypothesis.
4. Cellular structures in cooling liquids.
5. Liquid crystals.
6. The influence of surface tension.
7. Undercooling and the existence of a metastable limit.
8. Changes of volume on solidification.
9. The thrust exerted by growing crystals.

A few photomicrographs have been added for the purpose of illustrating certain points mentioned in the report, but the new experimental material is reserved for a later occasion. The report therefore concludes with an outline of the experi-

* *Molekularphysik*, 2 vols., Leipzig, 1888; *Flüssige Krystalle*, Leipzig, 1904; *Die neue Welt der flüssigen Krystalle*, Leipzig, 1911.

mental work undertaken or proposed for the purpose of testing
the hypotheses which are here described.

1. The Cellular Structure of Metals.

The granular structure of metals must have been more
or less vaguely recognized from an early period, from the
examination of fractured surfaces.   Their crystalline char-
acter   was   determined   microscopically   by   Hooke   in   the
seventeenth century,* whilst Réaumur, from observations of
the fractured surfaces of iron and steel, arrived at a distinct
conception of the internal polyhedral arrangement of the
metal.†   Modern advances in this direction have been made,
with few exceptions, by employing the method of etching
polished sections, first introduced in 1864 by Sorby, who had
previously applied similar methods with success to the ex-
amination of rocks and meteorites.‡   The subsequent de-
velopment of microscopical metallography is described in the
text-books of the subject.   Even the earliest records of the
appearance of microsections prepared by Sorby's method
notice the division of most metals into cells or crystal grains.
Attempts have been made, on various occasions, to distinguish
between cells of a first, second, and third order.   For example,
in a now familiar memoir on the cellular structure of iron
and steel, Osmond and Werth § distinguished simple cells,
bounded by carbide, and larger compound cells, composed of
dendritic crystals, in an ingot of high-carbon steel.   They
also laid stress on the importance of intercellular materials,
or "cements," in modifying the properties of the metal.   The
cellular structure of a variety of metals and alloys was ex-
amined from this point of view by Behrens,‖ by Arnold and
Jefferson,¶ and by Osmond and Roberts-Austen,** both of the
latter investigations dealing with alloys of gold, in which the

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* R. Hooke, *Micrographia*, London, 1665.
† R. A. F. de Réaumur, *L'Art de convertir le fer forgé en acier*, Paris, 1722.
‡ H. C. Sorby, *British Association Report*, 1864, vol. ii. p. 189.
§ F. Osmond and J. Werth, *Annales des Mines*, 1885 [viii.], vol. viii. p. 1.
‖ H. Behrens, *Das mikroskopische Gefüge der Metalle und Legierungen*, Leipzig, 1894.
¶ J. O. Arnold and J. Jefferson, *Engineering*, 1896, vol. lxi. p. 176.
** F. Osmond and W. C. Roberts-Austen, *Philosophical Transactions*, 1896, vol.
clxxxvii. *A*, p. 417 ; *L'Etude des Alliages*, Paris, 1901, p. 73.

effect of small quantities of impurity is very clearly marked. Andrews, in a study of wrought iron, distinguished primary, secondary, and tertiary crystals, the smallest of which would now be described as etch-figures.*

It is evident from a consideration of the facts alluded to below, and of the hypotheses which have been advanced for the purpose of explaining them, that more than one apparently cellular structure may be detected in metals under suitable conditions, and that much confusion has arisen from a failure to distinguish structures of different orders. Such a confusion is particularly to be observed in the array of evidence which has been brought forward in support of the foam-cell hypothesis, but it is also present in many other writings on the subject.

2. Crystallization from Centres and the Formation of Crystallites or Crystal Skeletons.

The opportunities of examining isolated crystals of the majority of the metals are comparatively few. With the exception of bismuth, the preparation of crystals of which by partial solidification of a molten mass is a familiar laboratory experiment, the metals do not readily yield well-defined crystals which can be separated from the mother-liquor. Our knowledge of the forms assumed by freely growing metallic crystals is therefore mainly derived from specimens found in the native state as minerals, or from crystals accidentally obtained in the course of manufacturing processes.

Native gold, silver, and copper, all of which crystallize in the regular system, frequently assume arborescent forms. Of these, the crystals of native copper from the Lake Superior region have perhaps been studied in the greatest detail.† Octahedral crystals are rare, and the most usual forms are those of the tetrakis-hexahedron, sometimes approaching the cube and the dodecahedron. More interesting than the simple forms, however, are the branched crystals, produced by the grouping of simple crystals along the axes of the cube, or

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* T. Andrews, *Proceedings of the Royal Society*, 1895, vol. lviii. p. 59.
† E. S. Dana, *American Journal of Science*, 1886 [iii.], vol. xxxii. p. 413.

along axes corresponding with the diagonals of an octahedral face.   A diagram of the first type is shown in Fig. 1.   As the branches of such arborescent crystals frequently meet at angles of $120°$, the symmetry is apt to be regarded as hexagonal.   The same effect is observed in polished and etched sections of many alloys, and intermetallic compounds have been described as crystallizing in the hexagonal system, when the symmetry is actually cubic, on account of the presence of dendritic crystals branching at angles of $60°$ or $120°$.   Native gold also frequently exhibits a similar pseudo symmetry.[*]
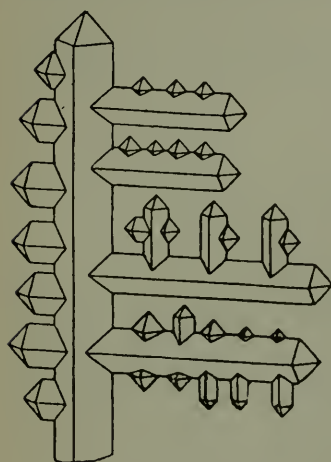
The earliest descriptions of artificial metallic crystallites refer to iron, and are due to a French ironmaster of the eighteenth century, Grignon, whose descriptions and drawings leave little to be desired on the score of accuracy.[†] The specimens were obtained from cavities in large masses of grey pig iron, which had cooled very slowly beneath a protecting layer of hot slag.   Fig. 2 reproduces the structure described by Grignon as typical of these isolated crystallites.   They are evidently formed by growth along the octahedral axes.   Very similar, although simpler forms, exhibiting branches at right angles, were obtained by the same author from masses of brass.

Fig. 1.

Grignon's results have been repeatedly confirmed, and the microscopical examination of etched transverse sections of similar crystallites, which are occasionally obtained in great perfection from the pipes of steel ingots, has verified the accuracy of the original explanation.

The next step in advance was made by Professor Tchernoff.[‡]

[*] E. S. Dana, *American Journal of Science*, 1886 [iii.], vol. xxxii. p. 132.

[†] Grignon, *Mémoires de Physique*, Paris, 1775 ; reproduced by Cartaud (see footnote on p. 64).

[‡] D. K. Tchernoff, *Revue Universelle des Mines*, 1880 [ii.], vol. vii. I. p. 129.   Published in Russian in 1878.

By examining sections of steel ingots this author was able to
show that the mass of the ingot is made up of crystallites
similar to those which are occasionally obtained growing
freely into a cavity. When, however, there is a constant
supply of liquid material, the development of the primary and
secondary axes is followed by that of axes of a higher order,
until the addition of fresh material gradually leads to the
obliteration of the spaces between neighbouring axes of the
same order. The external form of the crystallite then dis-
appears. If the metal of which it is composed be perfectly
homogeneous, all traces of the original arrangement disappear,
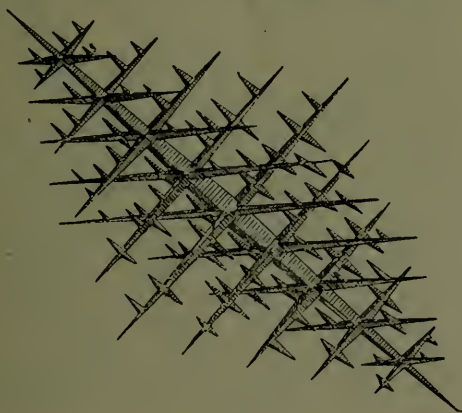
FIG. 2.

but the position of the axes is revealed by etching if, as is
usually the case, impurities are present which are rejected
during growth, thus becoming segregated at the external
boundary of the crystal.

The structure of steel ingots—and by extension that of
ingots of any other metal—may be completely accounted for
in this way. Crystallization first begins at the cooling surface,
and the first crystallites grow perpendicularly to that surface
into the mass of the liquid, becoming greatly elongated in the
direction of their principal axis. Thus is produced the
system of crystallites, perpendicular to the sides of the mould,
which is so well exhibited when steel, brass, or (to cite an
example frequently used in illustration of this point) antimony

sulphide is cast in a rectangular mould. In the interior of the liquid mass, especially if the cooling be rapid, crystallization may begin from numerous independent centres, each of which becomes the starting-point of a new crystallite, which may have any orientation whatever. The "crystal grains" of ordinary cast metals arise in this way, their boundaries being produced by the mutual interference of neighbouring crystallites, as indicated in Fig. 3.

The further investigation of the internal structure of large ingots of iron and steel has done much to elucidate the
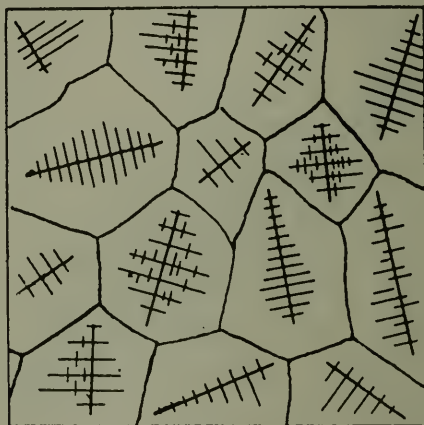
Fig. 3.

mechanism of the process of crystallization. Here it must suffice to mention the memoirs of Cartaud* and Belaiew.† Deep etching reveals the fact that the crystals of iron may be broken up into minute cubes, the structure being developed with remarkable perfection in silico-ferrite.‡ Copper yields octahedra when treated in a similar manner.

One of the most interesting peculiarities of the crystallization of metals is their tendency to assume the form of branched crystallites rather than of simple crystals. A salt, growing slowly and freely in a solution, generally preserves approxi-

* G. Cartaud, *Annales des Mines*, 1900 [ix.], vol. xvii. p. 110.

† N. T. Belaiew, *Crystallization, Structure, and Properties of Slowly Cooled Steel* (Russian), St. Petersburg, 1909.

‡ J. E. Stead, *Journal of the Iron and Steel Institute*, 1898, No. I. p. 145.

mately the same form during growth. A minute octahedron grows by the addition of solid material in directions parallel to each of the faces, so that the crystal retains the general form of an octahedron in spite of its increase in size. The constancy of form is not exact; new faces may make their appearance, and others may develop very unequally, so that the crystal assumes a tabular or an acicular form, but elaborate branching is the exception. On the other hand, most metals only exceptionally form simple polyhedral crystals, but by preference assume the form of branched crystallites.

A theory of crystallites was proposed by Vogelsang, who made a special study of these structures in vitreous rocks, such as pitchstone, in blast-furnace slags, and in artificial preparations.* He observed that by cooling solutions of sulphur in viscous solvents, minute spherical or oval globules were obtained, which then united to form chains, and then gradually developed crystalline outlines, so that the typical branched crystallites were thus produced. He therefore considered that crystallization always began by the formation of spherical solid masses, and regarded crystallites as " embryonic crystals." The view that the first stage of crystallization is the formation of a globular or " utricular " mass, also based on experiments with sulphur, had been previously suggested by Brame.† It has now been disproved, as it has been shown by many workers that the supposed solid globules of sulphur and other substances are in reality drops of under cooled liquid solutions, often of high viscosity. ‡

To decide whether the minute crystalline germ which first makes its appearance in a liquid has a globular form determined solely by surface tension or possesses a distinct polyhedral boundary is difficult, and different observers have recorded conflicting experiments. The question has, however, been set at rest for practical purposes in regard to salts by some studies of growing crystals by the method of instantaneous photography. § The photographs, mostly obtained

* H. Vogelsang, *Die Krystalliten*, Bonn, 1875.

† C. Brame, *Comptes Rendus*, 1853, vol. xxxvi. p. 463.

‡ See, for example, R. Brauns' *Neues Jahrbuch für Mineralogie, Beilag-Band*, 1899, vol. xiii. p. 39.

§ T. W. Richards and E. H. Archibald, *Proceedings of the American Academy*, 1901, vol. xxxvi. p. 341.

from barium chloride and potassium iodide, show that the crystal, from the first moment that it is able to produce an effect on the photographic plate, has a perfectly definite crystalline outline. As is shown in a later section of this Report, surface tension probably plays a much more important part in modifying the forms of metallic crystallites, not only in the earliest stages of growth, but also after a considerable complexity of growth has been attained. When such salts as barium chloride, copper sulphate, or lead nitrate are caused to crystallize very rapidly by the addition of alcohol, the minute crystals which are thus produced are perfect in form from the beginning.*

In experiments with salts, the formation of branched and dendritic forms in place of simple polyhedra is usually the result of very rapid crystallization, of high viscosity of the solution, or of the presence of colloidal material in suspension. None of these causes will suffice to explain the dendritic forms assumed by metals crystallizing from the molten state. The specimens obtained by Grignon had cooled very slowly, and the viscosity of molten metals is known not to be high. The mechanism of the growth of crystallites has, however, been satisfactorily explained, although the reasons why that mode of growth should present itself with certain substances still remain obscure. The principle of the explanation is mainly due to Lehmann.†

A crystal can only grow in a supersaturated solution. In the case of a molten metal, this is represented by liquid which is to a certain extent undercooled. In the immediate neighbourhood of a growing crystal there must be a zone of liquid which is no longer supersaturated, owing to the removal of the excess of dissolved substance. Further growth in this zone is impossible until its concentration has been increased by diffusion or by convection. The concentration thus depends on the rate of growth of the crystal, and on the rate of supply of dissolved material from the surrounding supersaturated solution. The presence of such a zone is easily observed in the crystallization of salts in thin layers on a microscope slide, and

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* P. Gaubert, *Bulletin de la Société française de Minéralogie*, 1902, vol. xxv. p. 223.

† *Molekularphysik*, vol. i. p. 337.

has been confirmed in the case of crystals growing freely in a mass of solution, by determinations of the refractive index.*

The "concentration currents" which are thus set up are strongest where the concentration gradient is greatest, and this is, as a simple geometrical construction will show, at the sharp angles of the original crystal. Hence growth at these angles is accelerated, and deposition of material there goes on with increasing velocity, resulting in the extension of the crystal along certain axes, having a regular arrangement about the centre. Should the supersaturation fall to such a point that growth of the crystal can only proceed with extreme slowness, the growth along axes ceases on account of the practical disappearance of the concentration currents, and further deposition of material takes place in such a way that the spaces between the branches are gradually filled up. These two stages of growth may be observed in the crystallization of many salts under the microscope. When the crystal is rapidly rotated during growth, a very regular polyhedral form is obtained.†

In the solidification of molten metals, each crystallite continues to grow until interfered with by the growth of another crystallite. Further solidification takes place between the branches, and finally, when the whole mass has become solid, the boundaries of the crystal grains are formed by mutual interference, as in Fig. 3. This is one way in which the cellular structure of metals may be accounted for. As each grain is, properly considered, a crystal (of the kind termed by mineralogists "allotriomorphic," that is, having an external form determined by the interference of adjoining crystals) the orientation of its component particles is uniform, whilst the orientation varies in different crystal grains. This is rendered evident by etching, and the familiar effect of etched metals illuminated obliquely is due to the orientation. It has also been found possible to determine the orientation from grain to grain by determining the polarization of the reflected light, and this method has certain advantages, but is not applicable to metals which crystallize in the regular system. It has been

* H. A. Miers, *Philosophical Transactions*, 1903, vol. ccii. *A*, p. 515.
† De Watteville, *Comptes Rendus*, 1897, vol. cxxiv. p. 400.

applied to the study of the groupings of crystallites in cast zinc, antimony, and bismuth.*

The form and dimensions of the crystal grains depend on number and arrangement of the nuclei from which crystallization begins. A metal solidifying in a thin layer, so that the nuclei may be considered to be in a single plane, and under such conditions that they are evenly distributed in that plane, will, assuming uniform velocity of growth in each direction, form crystal grains which are either quadratic or hexagonal prisms, having their prismatic axes perpendicular to the cooling surface. Of these, the hexagonal arrangement is the more stable (compare p. 80). In a large mass of metal, on the other hand, there are two modes in which the nuclei may be uniformly distributed, the cubic and the hexagonal,† and uniform growth from these as centres results in the formation of crystal grains of dodecahedral form, all the grains being similar, but the dodecahedra differing in shape in accordance with the presence of the cubic or the hexagonal arrangement.‡

The crystal grains in the interior of a slowly cooled ingot of cast metal have a form which sometimes differs surprisingly little from that which would be obtained under the ideal conditions supposed above. Towards the outside of the ingot the shape of the grains diverges very widely from that of the simple dodecahedron, as the nuclei are then situated at the cooling surface, and elongated crystallites are almost invariably formed. The regularity of distribution of the nuclei in actual cases depends on the uniformity of temperature throughout the mass, and on the absence of disturbing currents. Inequalities in the growth of the crystals in different directions also play their part in determining the form of the crystal grains. In the technical alloys, brass and bronze, the crystal grains depart very widely from the simple polyhedral form, and exhibit complex interlocking boundaries, which contribute largely to the strength of the metal.

* K. Endell and H. Hannemann, *Zeitschrift für anorganische Chemie*, 1913, vol. lxxxiii. p. 267.

† W. Barlow, *Nature*, 1883, vol. xxix. p. 186.

‡ W. Barlow and W. J. Pope, *Transactions of the Chemical Society*, 1907, vol. xci. p. 1150.

It has been assumed in the above discussion that crystalline growth continues until checked by actual contact with a neighbouring crystal. That this is the case has generally been assumed without discussion, but several investigators have been led to question its accuracy. The other view which may be taken is that crystal growth ceases when two neighbouring crystals are still separated by a sensible distance, that is, by a layer of more than molecular thickness, so that an amorphous " cement " intervenes between the grains. Such a cement must have many of the properties of a fluid, including viscosity. The hypothesis of a viscous, amorphous intercrystalline cement appears to have been first employed by Brillouin * in order to explain the behaviour of metals when subjected to deformation. The thickness of this layer would be determined by the fact, which the author believed to have established by experiment, that the molecules of a crystal are capable of exerting an influence which is sensible at five times the molecular distance, but probably insensible at eight or ten molecular distances.† This hypothesis was also employed by Sears ‡ for a similar purpose. It was independently reintroduced by Bengough § in order to explain the change of mechanical properties of metals with change of temperature, and has been adopted and elaborated by Rosenhain and his collaborators,‖ in whose hands it has developed into a working theory of the mechanism of deformation at different temperatures. As the theory has recently been ably summarized and defended, with references to the literature of the subject,¶ it is not necessary to discuss it further in this place. It should perhaps be pointed out that the well-known hypothesis of Beilby as to the production of an amorphous material in metals by mechanical deformation is independent of any assumption of an intercrystalline amor-

* M. Brillouin, *Annales de Chimie et de Physique*, 1898 [vii.], vol. xiii. p. 377.

† *Ibid.*, 1896, vol. vi. p. 540.

‡ J. E. Sears, *Transactions of the Cambridge Philosophical Society*, vol. xxi. p. 105.

§ G. D. Bengough, *Journal of the Institute of Metals*, No. 1, 1912, vol. vii. p. 176.

‖ W. Rosenhain and D. Ewen, *ibid.*, No. 2, 1912, vol. viii. p. 149, and later papers in that Journal and in the *Journal of the Iron and Steel Institute*.

¶ W. Rosenhain, *Engineering*, 1913: Paper read before Section B of the British Association at Birmingham. Somewhat extended in *Internationale Zeitschrift für Metallographie*, 1913, vol. v. p. 65.

phous layer as existing in metals in the normal, unstrained condition.

With the resources now available in such institutions as the National Physical Laboratory, it is possible to conduct experiments with metals at high temperatures from which such disturbing influences as that of oxidation are eliminated, and much light may be expected to be thrown on this part of the subject in the next few years.

The growth of crystallites from centres in the manner described above is not restricted to pure metals or solid solutions, whether growing in a liquid of similar composition or in a eutectic mixture. It is also characteristic of many eutectic alloys. Whilst the general microscopical appearance of these alloys is often strongly suggestive of an alternating mode of growth, there is now much evidence to show that the two constituents grow simultaneously, although usually with somewhat different velocities, from a centre.* The structures thus produced have the character of spherulites, and closely resemble the spherulites which are observed in the devitrification of glassy rocks.† A eutectic alloy has thus a tendency to arrange itself in masses which are completely analogous with, and have a similar appearance to, the crystal grains of pure metals or solid solutions. These compound grains have been termed " colonies," ‡ and are well seen in white iron, and in phosphor-bronze. § Their structure may be studied with facility in phosphor-copper. ‖ Quenching experiments have thrown much light on the mechanism of their growth,¶ especially in regard to the segregation which is brought about along the line of contact of the eutectic with crystallites of the metal in excess.

* W. Rosenhain and A. P. Tucker, *Philosophical Transactions*, 1908, vol. ccix. *A*, p. 89; R. Vogel, *Zeitschrift für anorganische Chemie*, 1912, vol. lxxvi. p. 425.

† W. Cross, *Proceedings of the Philosophical Society of Washington*, 1891, vol. xi. p. 411.

‡ C. Benedicks, *Internationale Zeitschrift für Metallographie*, 1911, vol. i. p. 184; W. Guertler, *ibid.*, 1913, vol. iv. p. 261.

§ O. F. Hudson and E. F. Law, *Journal of the Institute of Metals*, No. 1, 1910, vol. iii. p. 161.

‖ C. H. Desch, *Proceedings of the Royal Philosophical Society of Glasgow*, 1912, vol. xliii. p. 107.

¶ Unpublished experiments by F. E. E. Lamplough, communicated to Section B of the British Association, Birmingham, 1913.

3. Foam-Structures and Quincke's Hypothesis.

When two liquids which are only partially miscible are shaken together, an emulsion is formed, and when one of the liquids is in large excess, the other may become distributed in such a way as to form thin cell-walls, enclosing the drops of the first liquid. Such a structure is known as a foam. The experiment is easily tried by shaking benzene with a strong solution of potash soap, in which the soap solution forms the walls, enclosing drops of benzene. The form of the cells is definite, and corresponds with that determined by Plateau * in his beautiful experiments with froths, in which the cell-walls are of soap solution and the contents of air. A foam may possess considerable stability and even mechanical strength. For example, an emulsion may be prepared containing 99 per cent. of paraffin, and only 1 per cent. of a 1 per cent. solution of soap. The watery liquid then forms very thin cell-walls separating and enclosing the oil globules.† Such an emulsion forms a stiff jelly, which only de-emulsifies spontaneously in the course of many months, if kept in a closed vessel.

Professor Quincke has devoted much attention to the study of foams, using mostly solutions containing colloidal substances. Having found that cellular structures might be produced by the contact of two dissimilar liquids under a great variety of conditions,‡ and that a surface tension could be recognized in the surface of contact of two colloidal solutions of different concentration,§ he proceeded to the study of solutions free from colloidal material. The surface tension between ether and water changes with time, owing to the solution of ether by water, and of water by ether. If a thin stream of water flows into alcohol, the twisted stream forms which are observed indicate that a surface tension exists at the contact of the two liquids, but that it becomes less as the alcohol and water interdiffuse, vanishing when mixture is complete. If a concentrated salt solution be used in place

* J. Plateau, *Statique expérimentale et théorique des liquides*, Paris, 1873.
† S. U. Pickering, *Transactions of the Chemical Society*, 1907, vol. xci. p. 2001.
‡ G. Quincke, *Annalen der Physik*, 1902 [iv.], vol. vii. pp. 631, 701.
§ *Ibid.*, 1902 [iv.], vol. ix. pp. 793, 969.

of water, actual drops, as of oil in water, may appear, changing to stream forms as more and more dilute salt solutions are employed.* The conclusion is drawn from these experiments that there may be a surface tension at the contact of two solutions of the same salt, of different concentration, and that foams may therefore exist, in which the cell-walls differ from the contents only in the concentration of the dissolved salt. This view is considered to be supported by an elaborate series of experiments on the freezing of ice.† The small quantity of salts present even in distilled water furnishes the "oily" liquid for the foam-cells, the contents of which are pure water. The existence of the cells is revealed during melting by the formation of Tyndall's liquefaction figures. Repeated fractional melting and freezing, by eliminating dissolved impurities, increases the size of the foam-cells.

Crystals generally are regarded as foam-structures, differing only from the cells of colloids in the extreme minuteness of their cells.‡ Nevertheless, cleavage tends to take place along the cell-walls, so that a cleavage plane has the optical properties of a Japanese mirror, exhibiting minute rounded elevations, corresponding with the individual cells. This property is illustrated by the examples of quartz, specular iron, and other minerals.

Where three foam-walls meet one another, the angle between them is one of 120°. On the other hand, where a foam-wall meets a plane solid surface, the angle is one of 90°. It follows that, during the process of crystallization, angles of 120° are produced if three foam-walls meet while still liquid, but angles of 90° if one such liquid wall encounters one which has already become solid.

Plateau's soap solution, shaken in a flask, yields a froth with very regular cells, the properties of which are easily observed. A clear, colourless liquid, such as benzene, when allowed to freeze in a similar flask, and examined by a strong transmitted light, shows a division into grains which recalls the structure of a foam, the walls of which fulfil the primary condition of

* *Annalen der Physik*, 1902 [iv.], vol. ix. p. 1.
† G. Quincke, *ibid.*, 1905 [iv.], vol. xviii. p. 1; *Proceedings of the Royal Society*, 1905, vol. lxxvi. *A*, p. 431.
‡ *Berichte der deutschen physikalischen Gesellschaft*, 1903, vol. v. p. 102.

meeting at angles of 120°. Dendritic forms are obtained in the course of melting.*

Passing to metals, the crystal grains are regarded as foam-cells, the boundaries of which are the foam-walls. On this view, the coalescence of small grains to form larger ones during the process of annealing is a manifestation of the general tendency of foams to become coarser in structure. Further evidence for the hypothesis is derived from the corrosion of the boundaries of the crystal grains by etching reagents, pointing to a difference of composition between the foam-walls and their contents, and from the increased volatilization at the boundaries when metals are heated to a high temperature *in vacuo.*† The foam-structure is a complex one, as smaller foam-cells are indicated by etch-figures, casting pits, and other minor markings.

Foam-cells in metals are distinguished as of the first class if solidification has taken place before the liquid films assumed their position of equilibrium. They tend to have tubular, spiral, or branched forms, whilst foam-cells of the second class, produced in metals of lower viscosity, especially when the cooling is slow, approach more nearly to the form of the cells in a soapy froth. Crystallization within such cells frequently results in the formation of spherulites. The crystallization of a molten metal takes place periodically, not continuously, as the mass successively falls below the freezing-point, and is again warmed by the heat liberated by crystallization.

Even metals deposited from aqueous solutions of their salts are regarded as having a foam-cell structure. Beilby's amorphous layer due to mechanical deformation is not homogeneous, but consists of foam-tubes, warmed by friction and rapidly cooled by conduction, and in this way frequently converted into allotropic modifications.

It would occupy too much space to enter in detail into the applications of this hypothesis, and reference must be made to Quincke's recent paper, cited on p. 57. It is impossible to avoid the impression that the theory of foam-cells

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* G. Quincke, *Proceedings of the Royal Society*, 1907, vol. lxxviii. *A*, p. 60.

† L. Holborn and F. Henning, *Sitzungsberichte der Akademie, Berlin*, 1902, p. 936; W. Rosenhain and D. Ewen, *loc. cit.*

is made responsible for too much, and that a great variety of essentially different structures has been brought under the one head.   The hardening of metals, the formation of martensite in quenched steels, and some other metallurgical phenomena are explained in a somewhat forced manner.   Thus, a hardened steel is regarded as containing foam-walls of the thickness of only one-fifth of a light-wave, in which minute diamonds are imbedded.   It is also to be remarked that no quantitative test has been applied to the hypothesis, but that the descriptions and explanations of phenomena remain purely qualitative.   This defect is specially noticeable in regard to the question of crystals. No explanation of the geometrical properties of crystals, based on the hypothesis of foam-structure, has yet been given, and indeed it is not easy to see how any constant angles, other than those observed by Plateau in soap-films, could be produced.   As it is precisely the geometrical properties of crystals which have been most fully determined, and rest on the most firmly established scientific basis, this defect must be regarded as a serious one.

Another difficulty is of a physico-chemical character.   It has been proved experimentally that a true surface-tension exists between two liquids, such as water and alcohol, and some evidence has been produced in favour of the view that a similar tension exists in the surface separating two solutions of unequal concentration.   This is, however, a temporary phenomenon, disappearing as the solutions mix; it does not represent a state of equilibrium.   There is no reason why a liquid, originally homogeneous, should separate on cooling into two liquid phases, these two phases being miscible.   The process of mixture is an irreversible one.   It is, of course, possible for a liquid, homogeneous at a certain temperature, to separate into two immiscible liquid phases on cooling. Plate I. Fig. 6 shows a structure obtained by the slow drying of a homogeneous mixture of collodion with a vegetable oil on a glass slip.   As the solvent evaporates (a process comparable with the cooling of a hot solution) separation into two immiscible liquids takes place, resulting in the formation of a very distinct foam-structure.   In the assumed cases of metals and salt solutions, however, the two phases can be only solu-

tions differing slightly from one another in composition (in the case of highly purified metals, by an infinitesimal amount), and there is no reason to assume that they would be immiscible.

It is possible that these difficulties are not insuperable. The structure of some metals is such as to render the assumption of a foam-structure very tempting. Plate I. Fig. 7 represents a piece of cast 70 : 30 brass, in the unannealed condition. There is no second constituent here; but the *a*-solution, owing to imperfect equilibrium, exhibits coring, and the differences of composition between the cores and the periphery of the crystallites, as brought out by the action of the etching reagent, produce an effect which is very similar to that of an artificial foam.

It is not a sufficient objection to urge that Quincke's experiments have dealt with colloidal substances, the extension of the conclusions to crystalline substances proceeding by inference and analogy. There has been a marked tendency amongst chemists who deal with colloids to lessen the distinction between colloidal and crystalline substances. Thus, the electrical conductivity of solid solutions of metals has been accounted for, at least qualitatively, by the hypothesis that such substances are not homogeneous, but are colloidal systems of a high degree of dispersity,* and a tendency to revive this, the older, view as to the constitution of solid solutions, has shown itself independently.† Only experiment and microscopical observation can decide how far the foam-cell hypothesis, which has rendered good service in the study of amorphous, colloidal substances, may be legitimately extended to crystalline solids. It has been experimentally shown‡ that the crystal grains are not distorted when solidification takes place under the influence of centrifugal force, as might be expected to be the case on the foam-cell hypothesis.

4. Cellular Structures in Cooling Liquids.

An attempt has also been made by several recent writers to connect the cellular structure of metals and other solids with

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* P. P. von Weimarn, *Internationale Zeitschrift für Metallographie*, 1913, vol. iii. p. 65.

† C. A. Edwards, *Journal of the Institute of Metals*, No. 1, 1911, vol. v. p. 150; No. 2. 1911, vol. vi. p. 259.

‡ W. Rosenhain, *Nature*, 1913, vol. xci. p. 124.

a remarkable partitioning which is observed under certain conditions in cooling liquids. The earliest notice of a partitioning of this kind appears to be due to Weber, whose observations were not suspected to bear in any way on the question of crystallization. Weber * found that drops of a mixture of alcohol, gamboge, and water, if allowed to evaporate slowly on a glass slide, showed convection currents, and at a certain point the upper surface became divided into well-defined polygonal areas, which could be observed under the microscope. Weber's explanation of the phenomenon was incorrect; but Lehmann,† in discussing these observations, succeeded in interpreting them correctly. The upper surface of the liquid is cooled by evaporation, and the difference of temperature between the upper and lower surfaces then gives rise to convection currents, the warmer liquid ascending in a vertical column, spreading out radially at the top and then descending. The polygonal outlines are then the boundaries along which descending currents meet. (Weber had incorrectly supposed the liquid to ascend at the boundaries and descend in the centre.) The currents are rendered visible by the suspended particles of gamboge.

The drops of undercooled sulphur obtained by evaporating a solution of sulphur in turpentine have sometimes been observed ‡ to space themselves evenly. The cause of this arrangement was not at first realized, but later experiments have shown that each such drop represents the centre of a convection prism.

The first detailed study of this kind of partitioning is due to James Thomson, when Professor of Engineering in the University of Glasgow. Having observed a " tesselated " pattern on the surface of a vessel of soapy water, he succeeded in reproducing the conditions artificially and in demonstrating the origin of the structure.§ On filling a glass pan to a depth of 10 or 12 centimetres with soapy water the surface was seen to become tesselated, or divided into polygonal areas with

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* E. H. Weber, *Poggendorff's Annalen*, 1855, vol. xciv. p. 452.

† *Molekularphysik*, vol. i. p. 279.

‡ L. Frankenheim, *Poggendorff's Annalen*, 1860 [ii.], vol. cxi. p. 1.

§ *Proceedings of the Philosophical Society of Glasgow*, 1882; *Collected Papers*, 1912, p. 136.

distinct boundaries, the position of which was not constant but gradually changed, the larger areas absorbing the smaller and then again subdividing. It could be seen that each such area was the upper surface of a prismatic column, the convection currents due to cooling ascending in the central part of the column and descending along its walls. These convection currents were rendered visible by the insoluble particles, which give the characteristic pearly lustre to soapy water under suitable conditions.

Thomson's results did not become generally known, and although similar phenomena must have been frequently observed, very few observations of this nature have been recorded. The convection prisms have occasionally made themselves evident in a shallow bath of developing solution by their localized action on a photographic plate,* but without their true character being perceived. The first thorough study of the subject was made by Henri Bénard, who was unaware of the earlier work of Thomson.† Bénard's experiments were carried out with substances melting in the neighbourhood of 50°, which were consequently quite fluid at the temperature of the water bath. The best results were obtained with spermaceti. In order to obtain the greatest possible regularity of structure, a special form of heating apparatus was used, in which the liquid was exposed in a layer 0·4–2·0 millimetres thick in a metal trough 15 centimetres in diameter, so arranged that the lower surface, in contact with the metal, was constantly at a very uniform temperature. Under these conditions the prismatic arrangement of convection currents (*tourbillons cellulaires*) became extremely regular. When a steady state had been reached, the section of the prisms became hexagonal, the partitioning approaching more nearly to an arrangement of regular hexagons of equal size, the greater the care taken to eliminate disturbing influences.

Bénard devised several different methods for rendering the structure visible and recording it photographically. The simplest of these depends on the use of fine solid particles in suspension, and in this form the experiment is easily repeated.

* A. Guébhard, *Séances de la Société française de Physique*, 1897, p. 107.
† *Thèse pour le Doctorat*, Paris, 1901.

The particles may be lighter than the liquid; for example,
lycopodium spores, in which case a photograph, taken in-
stantaneously at a certain interval after strewing the sur-
face, shows very clear outlines of the polygons. On the other
hand, the particles may be heavier than the liquid, but of a
lamellar character, so that they are readily conveyed by the
convection currents, and betray by their change of lustre with
inclination the direction of their motion. The most suitable
solid particles for this purpose are those of graphite, especially
in the form of "kish" (Plate I. Fig. 8). Bénard's other
methods are optical in character, and depend on the difference
of level between the centre and periphery of the surface of a
convection prism. Satisfactory photographs have been obtained
by several such methods, and by combining the results a com-
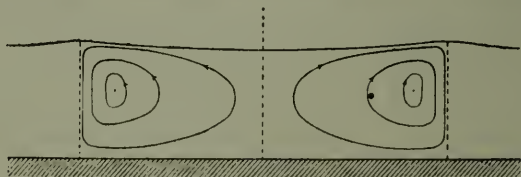plete insight has been obtained into the prismatic structure.

FIG. 4.

The distribution of the convection currents in a single prism
is indicated in Fig. 4. The centre of each polygon on the
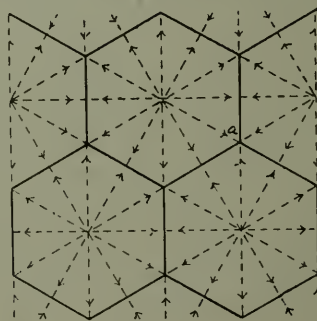

FIG. 5.

surface is a depression, whilst each point as *a* (Fig. 5), in
which three bounding lines intersect, is a summit. The

bounding lines themselves are ridges, the difference of height between the middle point of each ridge and a summit being about three-fourths of the difference of height between a summit and a depression. Consequently, particles of lycopodium tend to accumulate at the summits, whilst heavy particles are ultimately deposited in small conical heaps, each of which occupies the centre of the base of a prism—that is, the base of an ascending current. The differences of level increase with the thickness of the liquid layer, and with the difference of temperature between the upper and lower surfaces.

With layers of spermaceti of the order of a millimetre thick, the ratio of the depth e to the mean distance between the centres of two prisms, λ, that is $\frac{e}{\lambda}$, is approximately constant for a given liquid at a given temperature. Actually, the deviations of this ratio from equality have been observed to follow certain definite laws, an examination of which would, however, be beyond the scope of the present report. A relation between the values of this ratio and the other physical properties of the liquid has not yet been determined.

As the temperature of the liquid falls to the freezing-point, the movements become more sluggish, and the surface becomes more nearly plane, so that the prismatic structure is often completely obliterated before actual solidification takes place. This is not always the case, however, and in beeswax, or mixtures of beeswax with paraffin or salol, the structure is retained after solidification, so that the cells are easily examined and photographed.* With a layer 1 millimetre deep, the distance from centre to centre is of the order of 4 millimetres. Crystallization begins at the bounding surfaces of the prisms, and extends inwards.

The prisms thus produced are due to convection currents, brought about by differences of density between the warmer and cooler portions of the liquid; they are therefore always disposed vertically. When a test-tube containing molten spermaceti and fine graphite is immersed in a vessel containing water at a slightly lower temperature, vertical convection currents are at once set up, and it is not possible to produce

* C. Dauzère, *Journal de Physique*, 1907 [iv.], vol. vi. p. 892 ; 1908 [iv.], vol. vii. p. 390.

prismatic cells with their axes horizontal—that is, at right
angles to the cooling surface.   This appears to be a fatal ob-
jection to an explanation of the cellular structure of solid metals
by reference to Bénard's discoveries, as the external prismatic
crystals in cast metals are always perpendicular to the cooling
surface, and are independent of the direction of gravity.   It
is therefore somewhat surprising that two recent works on
metallography * † should have quoted these results without
remarking the fundamental distinction between the two cases.

When a metal solidifies in thin layers, it is quite possible
that prismatic convection cells may be formed, and may even
exercise a determining influence on the arrangement of the
crystal grains.   This may have some connection with the
" casting-pits " obtained with metals which have solidified in
contact with glass or mica,‡ and some experiments in this
direction, cut short by the early death of the investigator, were
made by Georges Cartaud. §   Metals are allowed to solidify
by pouring while molten on to an inclined slip of glass.
Whilst the surface of a thin layer of bismuth prepared in this
way is completely crystalline, that of lead, tin, zinc, or cad-
mium is marked with a reticular pattern, and crystallites,
when present, are built up of a number of·these small cells.
Occasionally, however, the boundary of a crystal grain cuts
completely across the boundaries of the cells.‖

The interpretation of Cartaud's observations is not easy.
The boundaries of his cells are marked by grooves, and not
by ridges, as in Dauzère's experiments with wax.   Further,
an examination of some of his photographs, especially of
Fig. 10 in the series published by Osmond, certainly suggests
that the supposed cells in relief have been produced by the
short axes of crystallites growing vertically in the metal, and
are therefore subsequent, and not anterior, to the formation
of the crystalline structure.   A repetition of some of these

* F. Robin, *Traité de Métallographie*, Paris, 1912.

† E. Heyn, *Metallographie* (vol. ii. of Martens' *Materialenkunde*), Berlin, 1912.

‡ J. A. Ewing and W. Rosenhain, *Philosophical Transactions*, 1899, vol. cxciii. *A*,
p. 353.

§ Republished, with photomicrographs added, by·F. Osmond, *Revue de Métallurgie*,
1907, vol. iv. p. 819.

‖ *Comptes Rendus*, 1901, vol. cxxxii. p. 1327.

PLATE I

FIG. 6.
Foam-structure in Mixture of Oil and
Collodion.
Magnified 5 diameters.

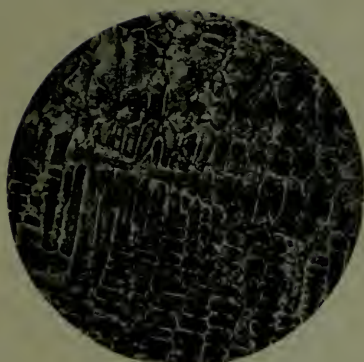

FIG. 7.
Cellular Structure in Cored α-Brass.
Magnified 40 diameters.

FIG. 8.
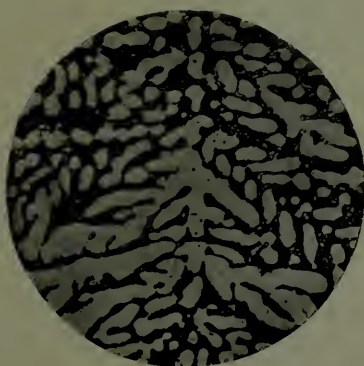Convection Cells in Liquid Spermaceti.
Two-thirds actual size.

FIG. 9.
Rounded Crystallites in Alloy containing
Aluminium 76%, Copper 24%.
Magnified 60 diameters.

experiments also produces the conviction that thin films of oxide exert a certain influence on the production of some of the patterns described. The close resemblance, noted in a later paper, * between certain cellular structures in metals and the patterns produced by the wrinkling or contraction of thin films of amorphous material, might be partly accounted for in this way. The relations between this cellular structure and the arrangement of the crystal grains revealed by etching is by no means a simple one, † and it is evidently impossible to assume, without further evidence, a causal connection between the convection cells and the crystalline structure.

5. Liquid Crystals.

The existence of substances which unite the properties of a crystal and of a liquid, although seemingly so improbable, has been established beyond doubt by the researches of Lehmann.‡ It is mainly organic substances which exhibit this behaviour, liquid crystals being formed by the cholesteryl esters of organic acids, by many azoxy-compounds, and by the alkali salts of the higher organic acids, especially those with branched chains.§ The crystalline structure is rendered evident chiefly by the optical properties, globules of the liquid acting on polarized light in such a way as to indicate a regular orientation of the molecules. Although the nature of these remarkable structures has been denied, and their properties attributed to the presence of two liquid phases in an emulsified state,‖ there appears to be no doubt that a definite arrangement of the molecules may, under certain conditions, persist in the liquid state, and this view is not now regarded as incompatible with the space-lattice theory of the constitution of crystals.¶

It is characteristic of liquid crystals that they behave as

* *Comptes Rendus*, 1903, vol. cxxxvi. p. 51.

† *Ibid.*, 1904, vol. cxxxix. p. 428.

‡ O. Lehmann, *Zeitschrift für physikalische Chemie*, 1889, vol. iv. p. 462. See the books by this author, referred to in footnote to p. 59.

§ D. Vorländer, *Berichte der deutschen chemischen Gesellschaft*, 1910, vol. xliii. p. 3120.

‖ G. Tammann, *Annalen der Physik*, 1905 [iv.], vol. xix. p. 421; G. Friedel and F. Grandjean, *Comptes Rendus*, 1910, vol. cli. p. 327.

¶ A. E. H. Tutton, *Crystallography*, London, 1911, p. 931.

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distinct phases, having a definite position in the equilibrium
diagram between determined limits of temperature.   There is
thus a definite temperature at which the solid phase passes
into the liquid-crystalline phase, and another higher tempera-
ture at which this again passes into the isotropic liquid
phase.   Some substances even pass through two liquid-crys-
talline phases before becoming isotropic, and in this case also
a definite transition temperature is observed.*   In binary
systems of substances which yield liquid crystals, the curves
which represent the variation of transition temperature with
composition have precisely the same general form as the curves
of freezing-point or of the transformation of solid phases.†

As the crystalline structure in such cases is only recogniz-
able by optical means, the formation of liquid crystals in
metals has not been observed.   Nevertheless, the suggestion
has been made on more than one occasion that some of the
phenomena which occur at or near to the melting-point of
metals may be connected with the formation of a liquid-
crystalline phase.   Thus, in some comments on Lehmann's
work, H. Le Chatelier ‡ drew attention to the analogy
between the growth of crystal grains in a metal on annealing
and the coalescence of the crystals of ammonium oleate,
referred to below.   A bolder suggestion was made by Car-
penter and Edwards. §   In the course of experiments with
alloys containing 90 per cent. of copper and 10 per cent. of
aluminium, these authors observed that remelting the alloy
was almost without effect on the composition or the mechanical
properties, but that the size of the α-crystals was modified to
a considerable extent, becoming greater in the second and
again in the third cast.   From these facts the conclusion is
drawn that: " . . . the growth of the crystals with successive
remeltings may constitute evidence that when crystalline
metals and alloys pass from the solid into the liquid state
they do not forthwith lose their crystalline character ; that

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* O. Lehmann, *Zeitschrift für physikalische Chemie*, 1906, vol. lvi. p. 750 ; F. M. Jaeger,
Proceedings of the Academy of Sciences, Amsterdam, 1907, vol. ix. p. 472.

† A. C. de Kock, *Zeitschrift für physikalische Chemie*, 1904, vol. xlviii. p. 129.

‡ Editorial, in *Revue de Métallurgie*, 1906, vol. iii. p. 105.

§ H. C. H. Carpenter and C. A. Edwards, Eighth Report to Alloys Research Com-
mittee, *Proceedings of the Institution of Mechanical Engineers*, 1907, p. 164.

although the chief attribute of the crystal, namely form, is lost, yet the essence remains in the shape of a systematic orientation of its material; that the crystal units persist in what is probably a very mobile condition, at any rate for a certain range of temperature above the melting-point."

This hypothesis has not remained without criticism. On the large scale, the remelting of alloys of copper with aluminium is usually necessary for the purpose of eliminating the tough pellicle of aluminium oxide which is formed by oxidation during melting and, by remaining suspended in the liquid metal, prevents complete adhesion between the crystals, and so reduces the strength and ductility of the alloy. That this factor did not produce any serious effect in the authors' experiments, which were conducted with small castings, is shown by the similarity of the mechanical properties of the three castings, shown in the following table :—

Sand Casting. No.	Per Cent. Copper.	Yield-point. Tons per Square Inch.	Ultimate Stress. Tons per Square Inch.	Per Cent. Elongation on 2 Inches.
1	90·15	11·7	31·90	26·5
2	90·10	10·8	31·92	29·2
3	90·18	13·0	30·77	22·5

There is thus no perceptible improvement in successive casts. Nevertheless, it is quite possible that minute films of aluminium oxide, insufficient to produce any appreciable weakening effect, might suffice to check the growth of the crystals, and such films would be eliminated on remelting. Further experiments are necessary to decide whether such films are actually present, whilst it is also desirable to determine, in the case of some readily fusible, transparent substance, the relation between the size of the crystals in the solid state and that of the liquid crystals into which they pass on fusion.

The crystals of ammonium oleate, to which allusion has been made above, differ from the liquid crystals of such substances as *p*-azoxy-anisole in this respect, that whilst the

latter when unconstrained become spherical, the former have a definite geometrical figure, that of a long, narrow double pyramid. When two such crystals come into contact, they coalesce to form a single crystal, having the same shape but twice the size. When a crystal of ammonium oleate is deformed by pressure, it returns to its original shape on removal of the pressure.* The bearing of these facts on the crystallization of metals is further discussed in the following section.

6. The Influence of Surface-Tension.

The influence of surface-tension in determining or modifying the forms assumed by metals and other substances during solidification has been taken into consideration by many who do not accept in its entirety the foam-cell hypothesis. That dendritic forms, closely resembling the crystallites of metals or of ice, may be produced by surface-tension in colloidal materials has been abundantly shown by the investigations of Lehmann and Quincke, and many workers with the microscope must have observed structures of this kind. An interesting recent study of the subject † utilizes films of viscous liquid between glass plates. On separating the plates at one corner, air enters, and the liquid retreats. The boundary between liquid and air in such cases is not simple, but assumes dendritic forms, the air dendrites, with rounded outlines, resembling those of many metals. With very viscous liquids, such as Venice turpentine, bubbles also appear in the mass of the liquid during separation, and these bubbles spread and branch, producing an appearance like that of eutectic colonies. The structures have only a temporary existence, and are recorded by means of instantaneous photography. The author draws attention to the close similarity between certain of the structures obtained in this way and the eutectic arrangement in white iron, the dendrites of austenite representing those of air, and the intervening cementite the films of liquid.

Whilst such analogies must not be pressed too far,' it is

* G. Quincke, *Annalen der Physik*, 1894 [iii.], vol. liii. p. 593.
† R. Arpi, *Arkiv för Matematik och Fysik*, 1912, vol. viii. No. 14.

impossible to resist the conclusion that surface-tension plays a part, and in all probability an important part, in determining the external form of metallic crystallites. Plate I. Fig. 9, which represents crystallites of the solid solution rich in aluminium in an alloy containing 24 per cent. of copper and 76 per cent. of aluminium, is typical of a very large number of alloys. The axes terminate, not in octahedral or similar sharp angles and plane faces, but in rounded expansions, suggestive rather of the shrinkage patterns of Arpi's experiments than of crystals. Such an effect is very frequently, but not invariably observed. Antimony separates from alloys containing 15 to 20 per cent. of copper in branched crystallites, terminated quite sharply, and some compounds are characterized by their sharp angles and a comparative absence of branching. The compounds SbSn, Fe_3P, and $CuAl_2$ are of this kind. The nature of the mother-liquor from which crystallization takes place, may have an influence on the form assumed by the primary constituent. Thus $FeSb_2$ crystallizes in rhombs if present in only small excess over the eutectic proportion, but in larger excess forms characteristic branched crystallites.

How far surface-tension is capable of modifying the shape of crystals is still a matter of some uncertainty. Quincke [*] attempted to determine the "capillary constant" of solid metals, but as the method adopted by him depended on the measurement of the strength of hard-drawn wires, the results cannot now be accepted, such wires now being known to be in part amorphous. [†] An important step was taken by Curie. [‡] A drop of liquid, so placed as to be free from the action of external forces, assumes, under the influence of surface-tension, the shape in which the surface is a minimum; that is, it becomes spherical. In similar manner, a solid crystal tends to assume that shape in which the sum of the surface energies is a minimum. As the different faces have different capillary constants, crystals do not become spheres, but strive to attain a condition in which the total surface

[*] *Poggendorff's Annalen*, 1868 [v.], vol. xiv. p. 356.
[†] See Dr. Beilby's papers, including summary cited on p. 57.
[‡] P. Curie, *Bulletin de la Société minéralogique de France*, 1880, vol. viii. p. 145.

has the minimum area compatible with the crystalline struc-
ture. It follows from this fact that, when crystals of various
sizes are placed in contact with a saturated solution of the
same substance, the smaller crystals tend to disappear,
the matter of which they are composed passing into solution
and being re-deposited on the larger crystals. Equilibrium
is only reached when the whole of the material has been
collected in one large crystal. This process, shown to be
theoretically necessary by Curie, does actually occur. It has
been most fully studied, from a quantitative point of view,
in aqueous solutions, and may be used to calculate the
surface-tension between a solid and a liquid,* but it also
occurs in solids. The segregation of the cementite lamellæ
in a pearlitic steel to form granules, or that of α-crystals
in a Muntz metal to form large plates, is a phenomenon of
exactly the same kind. So, also, is the growth of crystal
grains when kept at a favourable annealing temperature.†

The view that surface-tension may, under certain conditions,
overcome the crystallizing force was put forward in 1903 by
Dr. Beilby. ‡ The most favourable condition is that the
surface of the metal shall be large in proportion to its mass.
The larger the mass, the less is the influence of surface-
tension. Thin metallic films lend themselves well to the
demonstration of these phenomena. Faraday observed § that
thin gold or silver leaf supported on glass, which was nor-
mally translucent and brilliantly reflecting, was changed by
heating to a moderate temperature, becoming highly trans-
parent, but losing its high reflecting power. The study of
such films by means of the microscope shows that the effect
of heat, by increasing the molecular mobility of the metal,
is to cause the film to collect itself into aggregates, tending
to become globular. Evidently, a very thin film can more
readily undergo such a process than a thick one, as the surface
is very large in proportion to the mass. The condition thus

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* W. Ostwald, *Zeitschrift für physikalische Chemie*, 1900, vol. xxxiv. p. 495 ; G. A.
Hulett, *ibid.*, 1901, vol. xxxvii. p. 385.

† A summary of the literature on this subject is given by the writer, *Report of the
British Association*, 1912, p. 348.

‡ G. T. Beilby, *Proceedings of the Royal Society*, 1903, vol. lxxii. p. 226.

§ M. Faraday, *Philosophical Transactions*, 1857, p. 145.

produced, resembling that of a viscous fluid, is akin to that which exists on the surface of a metal strained by polishing.* In such a film, also, surface-tension is able to hold the crystallizing force in check.

The complete resemblance in this respect between the behaviour of a thin film of metal and one of a viscous liquid under the sole influence of surface-tension is well illustrated by a comparison between the forms assumed by gold or silver leaf on annealing and those assumed by a thin film of oil on water as it breaks up and collects to form globular aggregates. The similarity is very striking.†

It is possible to corroborate these conclusions abundantly from the mass of data published by Quincke, Lehmann, and Bütschli. Quite recently the theory of the subject has again been treated by Tammann,‡ whose conclusions are identical with those quoted above, but are expressed in precise mathematical form, confirmed by determinations of the tensile strength of metallic films at high temperatures.§ The formation of curved crystallites in binary mixtures is explained in the same way. Unfortunately, owing to our ignorance of the capillary constants of metals at different temperatures, it is not possible to subject the formulæ at present to quantitative verification.

A case in which the cohesive or directive forces are almost balanced by the surface-tension is that of the oleates and similar "fliessende Krystalle."‖ If two of the elongated, somewhat rounded crystals of potassium oleate are brought into contact in such a way that the long axis of one is at right angles to the other, they retain their position and form unchanged, except that the sharp end of the one crystal is flattened where it touches the other. On rotating one of the crystals so that their directions become more nearly parallel, deformation takes place, and union of the two crystals takes place at the junction. Then, with increasing velocity, one is

* G. T. Beilby, *Journal of the Society of Chemical Industry*, 1903, vol. xxii. p. 1166.
† G. T. Beilby, *Transactions of the Optical Society*, 1907, p. 22.
‡ G. Tammann, *Nachrichten der k. Gesellschaft der Wissenschaften, Gottingen*, 1912.
§ H. Schottky, *ibid.*
‖ O. Lehmann, *op. cit.* on p. 59, and *Zeitschrift für physikalische Chemie*, 1895, vol. xviii. p. 91.

absorbed by the other, until at last a single crystal is obtained, similar in form to the parents. The union is obviously the effect of surface-tension, and takes place in the same general way as the union of two suspended drops of oil in Plateau's experiments, with this difference, that the existence of a directive force in potassium oleate is rendered quite evident by the assumption of elongated forms, which are shown optically to belong to the tetragonal system. This is an extreme instance of the conditions which probably prevail in many alloys during the process of solidification.

7. UNDERCOOLING, AND THE EXISTENCE OF A METASTABLE LIMIT.

That a pure liquid may be cooled below its freezing-point without solidifying was first observed by Fahrenheit * in the case of water. The analogous phenomenon of supersaturation in salt solutions, that is, the undercooling of a binary system below the temperature at which a solid phase should make its appearance, was investigated by Lowitz,† who found that the supersaturation could be removed by introducing a crystal of the same salt, but not of a foreign substance. The subsequent history of the subject has been described very fully by Ostwald,‡ who, however, does not notice the earliest English work on the undercooling of metals. The cooling of mercury several degrees below its freezing-point without crystallizing was observed in the course of experiments carried out at Hudson's Bay,§ and was confirmed by Cavendish, who was unable to detect any undercooling of molten tin or lead, although he considered that such must occur, at least to some small extent.‖ The "flashing" of gold beads during cupellation, which had been long familiar to assayers, was not shown to be due to the crystallization of an undercooled liquid until much later.¶

* D. G. Fahrenheit, *Philosophical Transactions*, 1724, vol. xxxix. p. 78.

† J. T. Lowitz, *Crell's Chemische Annalen*, 1795, vol. i. p. 3.

‡ W. Ostwald, *Lehrbuch der allgemeinen Chemie*, 1896–1902, vol. ii. Part 2, Sect. i. pp. 379, 704.

§ T. Hutchins, *Philosophical Transactions*, 1783, vol. lxxiii. p. 303* (double paging).

‖ H. Cavendish, *ibid.*, p. 303.

¶ A. D. van Riemsdyk, *Annales de Chimie et de Physique*, 1880 [v], vol. xx. p. 66.

The first accurate measurements of the extent of under-cooling in metals are due to Roberts-Austen,[*] who used a photographic method of recording the cooling curves, and obtained very sharp and definite records of the process of freezing. Gold was undercooled to the extent of $3°$, and copper to $7°$, whilst some alloys of lead and tin showed a rise of $11°$ when crystallization set in. The experiments did not decide whether liquid metals could be maintained for any length of time in the undercooled condition, and evidence was obtained for the view that crystallization was often started by the deposition of minute crystals directly from the vapour.

The size of the crystalline particle which is capable of initiating crystallization has not been determined for metals, but some extended experiments have been made with salts, and also with organic substances, especially salol.[†] The latter substance, which can be long preserved in an undercooled condition, lends itself well to such experiments. By grinding salol with increasing quantities of finely powdered quartz, mixtures of increasing dilution could be obtained, until at last a dilution was reached at which the power of initiating crystallization disappeared. The limit for salol was found to lie near to 10^{-8} gramme of the solid, whilst the quantity of sodium chlorate which would bring about the crystallization of a supersaturated aqueous solution was considerably smaller, namely 10^{-10} gramme. The difference was attributed to the volatility of salol.

Ostwald has concluded, on theoretical grounds, that there are two stages of undercooling or supersaturation (the conditions in one- and in two-component systems being fundamentally alike), and that these stages are probably separated by a definite boundary. A liquid which is so far undercooled as to be incapable of crystallizing spontaneously, but which crystallizes when brought into contact with a particle of the solid phase, is termed *metastable*, whilst a further degree of undercooling renders the liquid liable to spontaneous crystallization, and it is then termed *labile*. The existence of a

definite boundary between these two regions of instability, the *metastable limit*, has been denied by Tammann,* who considers that they pass continuously into one another. The principal experimental evidence relied upon by Ostwald was that furnished by Liesegang's phenomenon.† When silver nitrate diffuses into a jelly containing potassium dichromate, the silver chromate which is precipitated does not form a continuous deposit, but arranges itself in parallel bands at regular intervals. Thus, if a drop of silver nitrate be placed in the middle of a plate of dichromated gelatin, the silver chromate is deposited in concentric rings of crystals, separated by clear spaces. A similar effect is obtained with many other substances. The only satisfactory explanation which has been proposed depends on the existence of a metastable limit. As the silver nitrate diffuses outwards silver chromate is formed, but remains in metastable solution until the limiting concentration is reached, when crystals are suddenly deposited, withdrawing the salt from the gelatin through an appreciable distance. The nitrate then diffuses further, and the reaction is repeated in a zone exterior to the first rings. As the silver nitrate becomes more dilute as it extends further from the centre, so the distance between successive rings increases regularly.

The earlier attempts to decide the question by direct experiment failed by reason of the difficulty of preventing accidental contamination by crystallizing particles, and of determining the exact degree of undercooling in the neighbourhood of growing crystals. Both difficulties have been overcome in the brilliant investigations of Miers and his collaborators.‡ Determinations of the refractive index have been employed to ascertain the concentration of the solution at different points. These experiments show that for each substance there is a definite temperature, lower than the freezing-point, above which inoculation with the solid

* *Kristallisieren und Schmelzen*, Leipzig, 1903.

† R. A. Liesegang, *Chemische Reaktionen in Gallerten*, Düsseldorf, 1898; *Ueber die Schichtungen bei Diffusionen*, Leipzig, 1907.

‡ H. A. Miers and F. Isaacs, *Transactions of the Chemical Society*, 1906, vol. lxxxix. p. 413; and later papers in that journal and in the *Proceedings of the Royal Society*. Well summarized in *Science Progress*, July 1907.

phase is necessary to induce crystallization, whilst below it crystallization can begin spontaneously. The same is true of binary systems, so that it is possible to draw, below and approximately parallel with the solubility curve, a *supersolubility curve*, which shows the relation between the metastable limit and the concentration. This has been verified for a number of pure substances and mixtures, including systems in which solid solutions are formed, and in which the solid may crystallize in several polymorphic modifications. Corresponding determinations have not yet been made with metals or alloys.

There still remains the possibility that a metastable liquid may be caused to crystallize in some other way than by the introduction of a solid crystal, but that the operation is so difficult that shaking, scratching, and similar devices employed in experiments of this kind are insufficient to provide the necessary stimulus. If this should be the case, it would be possible in some measure to reconcile the views of Ostwald and Tammann. A remark of Miers in this connection may be quoted :

" If the growth of a crystal is really the coming together of vibrating particles which cohere because they are in tune with one another, . . . then is it not possible that we may be able to communicate these vibrations to a supersaturated solution, which is so densely crowded that it is ready to crystallize, by some other means than by inoculating it with the appropriate crystal ? " *

This expectation appears to be fulfilled.† It has been found possible to make water, benzene, or salt solutions crystallize when in the metastable condition by applying mechanical shocks of sufficient intensity, by means of metallic hammers striking on hard metallic anvils. With a sufficient intensity of the repeated blows, water may be caused to crystallize without the addition of ice when the undercooling is as little as $0.02°$.

The extension of such experiments to the metals is attended

* H. A. Miers, *The Growth of a Crystal* (Robert Boyle Lecture, Oxford, 1911).

† S. W. Young, *Journal of the American Chemical Society*, 1911, vol. xxxiii. p. 148 ; S. W. Young and R. J. Cross, *ibid.*, p. 1375 ; S. W. Young and W. van Sicklen, *ibid.*, 1913, vol. xxxv. p. 1067.

by considerable difficulty, occasioned in large part by the absence of transparency ; but the existence of a metastable limit in metals should be capable of experimental verification. It should be said that there is no evidence of a mass of liquid metal being so far undercooled as to form a glass, that is, to assume a rigid amorphous condition, although this condition has been observed in water. The vitreous water passes at once into crystalline ice when scratched with a needle, and is therefore labile.*

Miers' experiments have shown that the habit of crystals is different according as they have separated from a metastable or a labile solution. The fact that the formation of spherulites is dependent on crystallization under labile conditions † may have some bearing on the origin of certain structures in alloys.

A few isolated experiments with metals have been published, the object of which was to discover the relation of the number of centres produced in spontaneous crystallization to the degree of undercooling. The experiments were confined to bismuth and antimony,‡ and the method adopted was that of pouring the molten metal, previously heated to a definite temperature, into a mould kept at constant temperature by means of a bath. After solidification the number of crystal grains in a given area was counted, this being a measure of the number of centres of crystallization. The temperature of the mould was varied in different experiments from above the melting-point of the metal down to − 70°. The method is faulty, because it gives no information as to the extent of undercooling. A cold mould increases the rapidity of the cooling, but crystallization undoubtedly sets in before the metal reaches the temperature of the mould. It is perhaps legitimate to infer that the undercooling will be more considerable the greater the difference of temperature between the mould and the metal at the time of pouring ; but the two magnitudes are not necessarily in direct proportion to one another.

* G. T. Beilby, May Lecture, 1911, *Journal of the Institute of Metals*, 1911, No. 2, vol. vi.

† J. Chevalier, *Mineralogical Magazine*, 1909, vol. xv. p. 224.

‡ E. Bekier, *Zeitschrift für anorganische Chemie*, 1912, vol. lxxviii. p. 178.

It was found that the crystal grains became smaller (that is, the centres more numerous) the greater the rapidity of cooling; but at the lowest temperatures examined the number of centres once more increased in the case of antimony, but not in that of bismuth. This was considered to show that antimony lost its power of crystallizing spontaneously at low temperatures; so that, with a sufficient degree of undercooling, it might conceivably be obtained in an amorphous condition. Amorphous antimony has in fact been obtained by condensing the vapour of the metal very rapidly by contact with a surface cooled by liquid air.* This may, however, be merely the effect of deposition in minute globules, the size of which allows them to assume forms governed by surface tension. Many metals may be obtained in the form of minute globules by electrical dispersion (*Zerstäubung*) or sublimation.†

8. CHANGES OF VOLUME ON SOLIDIFICATION.

The change from the liquid to the solid state is usually accompanied by a change of volume. The density of a solid metal may be either greater or less than that of the liquid metal at the same temperature, and instances of both conditions are known to occur. The experimental determination of the change of volume is accompanied by serious difficulties where metals of high melting-point are concerned. Similar difficulties present themselves in the study of minerals and rocks, in which a knowledge of the change of volume on solidification is of importance for geology; but here they may be in part overcome by resort to an expedient. Many minerals and rocks may be obtained in the state of glass by rapid cooling from above the melting-point, and a comparison of the density and coefficient of expansion of the crystalline solid with those of the glass, which are continuous with the corresponding properties of the liquid, furnishes the information with a fair degree of certainty. This device is not applicable

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* A. Stock and W. Siebert, *Berichte der deutschen chemischen Gesellschaft*, 1905, vol. xxxviii. p. 3837.

† V. Kohlschütter and C. Ehlers, *Zeitschrift für Elektrochemie*, 1912, vol. xviii. p. 373.

to metals, which cannot be brought in mass into the form of glass, and direct measurements, therefore, become necessary.

It was formerly thought that the solid substance must necessarily have a greater density than the liquid at the same temperature, on the ground that the solid state corresponds with the most closely packed arrangement of the molecules. This opinion was challenged by Duvernoy,[*] who observed that many metals, when allowed to solidify in glass tubes, burst the tubes, thus indicating an expansion (diminution of density) during the act of freezing. Duvernoy's results were somewhat variable, and led him to conclude that the volume change is dependent on the rate of cooling, so that pure zinc or tin, for example, may contract during solidification if cooled rapidly, but will expand if cooled slowly. For reasons which are discussed in the next section, observations of this kind prove nothing as to the direction of the volume change.

The density of liquid metals has been determined [†] [‡] [§] by filling a vessel, the capacity of which at the temperature of the experiment is known, with molten metal. The vessel is then weighed. In this way the difference of density between the cold solid and the hot liquid metal is obtained, but a knowledge of the exact expansion of the solid metal up to its melting-point is necessary before the actual change of temperature at that point can be determined. As carried out before the introduction of silica dilatometers, the method was not susceptible of high accuracy. Metal containing-vessels were used, which became permanently distorted as the result of heating and cooling, and it was impossible to determine the volume at the moment of freezing exactly. The density of the liquid metal could, however, be determined approximately in this way, and the data so obtained have proved to be of some value.

From the time of Réaumur onwards, it has been observed that masses of solid metal will frequently float when thrown into a vessel containing the same metal in a molten condition.

* G. Duvernoy, *Neues Jahrbuch für Mineralogie*, 1852, p. 781.

† L. Playfair and J. P. Joule, *Memoirs of the Chemical Society*, 1845, vol. ii. p. 401.

‡ R. Mallet, *Proceedings of the Royal Society*, 1873, vol. xxii. p. 366; 1874, vol. xxiii. p. 209.

§ W. C. Roberts (Austen), *ibid.*, 1874, vol. xxiii. p. 481.

This has been recorded for iron, copper, silver, gold, antimony, and lead, and has occasionally been cited as evidence that such metals are lighter in the solid than in the liquid state, but this is by no means necessarily the case. Mallet showed that the flotation did not always correspond with any true buoyancy of the solid, and explained it by the influence of convection currents. Actually, several different causes may combine to produce the effect. Flotation has been used as a means of determining the density of liquid metals. Thus the method commonly adopted by mineralogists of determining the density of solid particles which just sink or just float in the liquid has been applied to metals.* For measurements with tin the solid masses employed were lumps of tin, in which copper was enclosed to increase their density. This method led to very incorrect conclusions. Obviously, the first condition of the mineralogical method, that the solid particles should not be acted on by the liquid, is not here fulfilled.

A special form of instrument, the oncosimeter, was also devised, in which the force acting on a metal ball suspended in the liquid metal by a spiral spring was measured.† In this way it was shown that grey cast iron and bismuth expand on solidification, whilst copper, silver, lead, tin, and zinc contract.

More satisfactory results have been obtained by means of the dilatometer, which has hitherto been usually of glass, but may now be advantageously constructed of silica. The principal difficulty in making such determinations is that of finding a suitable filling liquid. Molten metals are inapplicable, on account of their miscibility with the metal which is being studied, whilst oils and other organic substances decompose or volatilize at relatively low temperatures, restricting the experiments to the more readily fusible metals. The use of fused salts should here present some advantages.

The first metals which were shown in this way to contract on freezing were sodium and potassium ‡ and tin. §   A more

* F. Nies and A. Winkelmann, *Annalen der Physik*, 1883 [iii.], vol. xviii. p. 364.

† W. C. Roberts (Austen) and T. Wrightson, *Philosophical Magazine*, 1881 [v.], vol. xi. p. 295 ; 1882 [v.], vol. xiii. p. 360.

‡ E. Hagen, *Verhandlungen der deutschen physikalischen Gesellschaft*, 1882, vol. i. p. 94.

§ E. Wiedemann, *Annalen der Physik*, 1888 [iii.], vol. xx. p. 228.

extended series of measurements * included the determination of the density and of the coefficient of expansion of both the solid and the liquid metal in the case of lead, cadmium, tin, and bismuth, expansion during solidification being clearly proved to occur in the case of the last-named metal. The volume changes of bismuth were also studied in detail,† and it was found that this metal resembles water in having a maximum density at a temperature just above its melting-point. On cooling below this temperature, therefore, the liquid undergoes slight expansion, followed by a much larger expansion as the metal freezes. The change of volume is, however, much smaller than in the case of water.

The dilatometric method was further improved by Toepler, ‡ who studied a larger number of elements, and took the important precaution of ensuring that solidification of the metal proceeded slowly from below upwards, in order to guard against the formation of internal cavities. The results hitherto obtained by these observers are summarized in the following table :—

Metal.					Percentage Increase of Volume on Melting.		
Sodium	.	.	.	.	2·5 (T).	2·5 (H).	
Potassium	.	.	.	.	2·5 (T).	2·6 (H).	
Tin	.	.	.	.	2·8 (T).	2·8 (V and O).	
Cadmium.	.	.	.	.	5·2 (T).	4·72 (V and O).	
Lead	.	.	.	.	3·7 (T).	3·39 (V and O).	
Thallium .	.	.	.	.	3·1 (T).		
Zinc .	.	.	.	.	0·9 (T).		
Aluminium	.	.	.	.	4·8 (T).		
Tellurium.	.	.	.	.	7·3 (T).		
Antimony.	.	.	.	.	1·4 (T).		
Bismuth .	.	.	.	.	−3·27 (T).	−3·31 (V and O).	−3·0 (L).

The initials in brackets refer to the authorities quoted in the footnotes, and it will be seen that the agreement between the results obtained by different observers is very satisfactory.

The change of volume on solidification was found by Toepler to be a periodic function of the atomic weight, and the curve

exhibiting the relation is very similar in form to the atomic volume curve.

Organic substances have been examined with much greater precision than metals. In a recent investigation * the substances examined were enclosed in capillary tubes sealed at one end, and immersed in a bath the temperature of which was only very slightly below the freezing-point of the substance. In this way freezing may be made very gradual, the process occupying many days, so that the formation of cavities in the solid· is avoided. The level of the upper surface of the solid having been noted, the substance is melted and the level again determined. Subsequent calibration of the tube with mercury gives the change of volume directly. The results obtained in this way are in excellent agreement with those found by the indirect method of determining the density of the solid and the liquid metal at temperatures not far removed from the freezing-point. It is very desirable that determinations of this kind should be extended to metals.

For most substances hitherto examined, Tammann's relation holds good :—

$$\delta v = T_{\text{o}}\left(\frac{dv'}{dT} - \frac{dv''}{dT}\right)$$

where δv is the change of volume on fusion in cubic centimetres per gramme, T_{o} is the absolute temperature of fusion, and

$$\frac{dv'}{dT} \text{ and } \frac{dv''}{dT}$$

are the changes of volume, in cubic centimetre per gramme, of the liquid and solid respectively per degree C.

Very few alloys have been studied in this way. Hagen examined the liquid eutectic of sodium and potassium, and Roberts-Austen examined Levol's alloy, the eutectic of silver and copper, finding that it behaved similarly to the pure metals. Wiedemann found that the eutectic of lead and tin expanded 2 per cent. of its volume on melting, and that alloys of lead and bismuth expanded or contracted according to the proportions of the component metals.

It is also necessary to discuss a series of experiments bear-

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* H. Block, *Zeitschrift für physikalische Chemie*, 1912, vol. lxxviii. p. 385.

ing on this question, but based on a different principle. For the practical purposes of the foundry it is important to know how far a finished casting will differ in size from the pattern used in preparing the mould. The contraction of the solid metal during cooling is allowed for by making the pattern slightly larger than the casting is required to be, the ratio being determined by experiment. The contraction is usually expressed as a linear fraction, such as " $\frac{1}{8}$ inch per foot," instead of, as in the above laboratory experiments, as a volume ratio.

An apparatus for this purpose was devised by Keep,* and improved by Turner.† The metal to be tested is cast in a sand mould, in the form of a T-shaped bar, one end of which is held by a fixed pin, whilst the other is in contact with a freely movable rod attached to an extensometer. The pouring gate is on one of the branches of the T, and a thermocouple is inserted at a convenient point. In later work with this apparatus, a chronograph has been used for the purpose of recording the variations of temperature and of length with time more exactly. In its most recent forms, the instrument is very sensitive.

As long as the metal in the mould is liquid, no record is made by the instrument, provided that the movable rod has sufficient friction to resist the thrust due merely to the weight of liquid metal, but the extensometer indicates all changes which take place after solidification has proceeded so far that there is a rigid connection between the fixed and the movable pin.

It is evident that the records of such an instrument do not necessarily correspond with those of the dilatometer. The volume of liquid metal is undefined, as there is a gate in which the liquid can rise and fall to compensate for variations in the volume of metal in the mould. Moreover, as is shown in the next section, many metals, especially those which do not crystallize in the regular system, are capable of exerting a considerable thrust in the direction of one axis during growth, forcing themselves apart in the process and simulating

* W. J. Keep, *Journal of the Iron and Steel Institute*, 1895, No. II. p. 227.
† T. Turner, *ibid.*, 1906, No. I. p. 48, and papers cited below.

expansion. In dilatometric measurements, this complication has to be guarded against as completely as possible by allowing cooling to occur very slowly and progressively along the length of the containing vessel, so that cavities as they are formed are filled up, either by the liquid metal or by the fluid used to fill the capillary of the dilatometer. This is impossible in the present instrument, in the mould of which the metal crystallizes irregularly, and cavities may remain unfilled. In point of fact, the test-bars often reveal a considerable degree of porosity when examined under the microscope. It is also impossible, in this method of working, to eliminate the influence of dissolved gases.

A similar instrument has been employed by Wüst.* In this form, however, there is no fixed pin, and the two ends of the bar solidify around sliding rods which actuate pistons, the changes in length being indicated by the displacement of a column of liquid. The same criticisms of the method are applicable here.

Professor Turner and his students have obtained some very interesting results in the course of experiments with the mould and extensometer, some of which are difficult to explain without further investigation.†–|| Copper, tin, lead, and bismuth were found to solidify without expansion, whilst zinc, aluminium, and antimony were observed to expand. These results cannot be accepted without some hesitation. Dilatometric measurements, which are necessarily more trustworthy owing to the elimination of disturbing factors, clearly prove that whilst tin and lead contract during solidification, bismuth expands. The apparent expansion of aluminium is attributed by Chamberlain to the influence of dissolved gases, and Wüst has observed a similar effect in copper. Effects of this kind may be disregarded, but there remain some remarkable cases of apparent expansion during solidification, indicated by movements of the extensometer. In such cases

* F. Wüst, *Metallurgie*, 1909, vol. vi. p. 769.

† T. Turner and M. T. Murray, *Journal of the Institute of Metals*, No. 2, 1909, vol. ii. p. 98.

‡ D. Ewen and T. Turner, *ibid.*, No. 2, 1910, vol. iv. p. 128.

§ T. Turner and J. L. Haughton, *ibid.*, No. 2, 1911, vol. vi. p. 192.

|| J. H. Chamberlain, *ibid.*, No. 2, 1913, vol. x. p. 193.

a general correspondence has been observed between the amount of expansion and the " crystallization interval "—that is, the vertical range of temperature between the liquidus and solidus curves in the equilibrium diagram. Very large expansions were observed in the freezing of an alloy of 15 per cent. copper and 85 per cent. zinc. In this case the expansion begins at 590°, the temperature of formation of ϵ-crystals from δ-crystals and liquid, and continues until the mass is completely solid at about 420°. The effect is thus connected with the formation of a new solid phase from the liquid and the solid phase initially deposited. Some of the alloys of copper with large proportions of aluminium also give large apparent expansions. The reasons for doubting whether the results are in all cases due to actual increase of volume are dealt with in the next section.

Experiments in the dilatometer have not yet been made with metallic solid solutions, or with intermetallic compounds, so that a comparison of the extensometer results with those of the control method is not yet possible. As regards eutectics, the extensometer records a small expansion in several cases. The eutectics mentioned on p. 97 contract, like their component metals, on solidification, but it is quite possible for a eutectic, composed of two metals which contract, to solidify with increase of volume, although the occurrence of such an expansion awaits experimental verification.*

Whatever may be the theoretical significance of the results obtained with the extensometer, there can be no doubt of the value of its indications for the practical work of the foundry. The increase in external dimensions of the test-bar before contraction sets in is a fact, and one of importance in the practical casting of the alloys in question, as it affects the allowance to be made in constructing the pattern. Moreover, these investigations, if they have not solved the problem of the changes of volume in the solidification of alloys, have raised many questions of high scientific interest, and have pointed the way to new knowledge.

Some of the expansions observed are no doubt due to re-

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* H. W. Bakhuis Roozeboom, *Die heterogenen Gleichgewichte* (Brunswick, 1904), vol. ii. I. p. 416.

actions between previously existing phases or to the decomposition of such a phase. The principal expansion in the solidification of grey cast iron is due to the liberation of graphite, a solid phase of high specific volume, and such cases as that mentioned above, of the $\delta\,\epsilon$ alloys of copper and zinc, may be partly accounted for in the same way. There still remains, however, an important residue of anomalous observations, which still await explanation.

Qualitative, if not quantitative, evidence of the change of volume at the melting or freezing point is also furnished by measurements of the electrical conductivity of metals in the liquid and solid states. The conductivity of solid metals is increased by pressure,* and the same is true of liquid mercury.† Therefore, as Tammann has pointed out, the conductivity should increase at a change of state accompanied by diminution of volume, and decrease when the volume increases. The data at present available on this point confirm the conclusions already arrived at by means of the dilatometer, the single exception hitherto being antimony, as to which considerable uncertainty still prevails, owing to its anisotropic character, which renders its crystallization very liable to vary irregularly.

The data are collected in the table, the authorities being given in the footnotes ‡–§§. The specific resistance has been used in place of the conductivity.

Only a few alloys have been examined in this way. Northrup found that the eutectic alloy of sodium and potassium behaved like its component metals, and the solid solutions of copper and nickel have been found to increase in

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* O. Chwolson, *Beiblätter der Physik*, 1881, vol. v. p. 449; author's abstract from Russian publications.

† R. Lenz, *ibid.*, 1882, vol. vi. p. 882, from separate publication.

‡ A. Matthiessen, *Poggendorff's Annalen*, 1857 [iv.], vol. x. p. 177. (Communicated by G. Kirchhoff.)

§ W. Siemens, *ibid.*, 1861 [iv.], vol. xxiii. p. 91.

‖ L. de la Rive, *Comptes Rendus*, 1863, vol. lvii. p. 698.

¶ G. Vincentini and D. Omodei, *Atti R. Accademia delle Scienze di Torino*, 1889, vol. xxv. p. 30.

** G. Vassura, *Nuovo Cimento*, 1892 [iii.], vol. xxxi. p. 25.

†† E. F. Northrup, *Transactions of the American Electrochemical Society*, 1911, vol. xx. p. 185.

‡‡ L. Grunmach, *Annalen der Physik*, 1888 [iii.], vol. xxxv. 764.

§§ L. P. Cailletet and E. Bouty, *Journal de Physique*, 1885 [ii.], vol. iv. p. 300.

resistance on melting, indicating that the solid is denser than the liquid at the melting-point.*

Metal.					Resistance of Liquid / Resistance of Solid at Melting-point.			
Sodium	.	.	.	.	1·35 (M)	1·47 (N)		
Potassium	.	.	.	.	1·36 (M)	1·54 (N)		
Tin	.	.	.	.	2·2 (d 1 R)	2·21 (V and O)	2·1 (S)	2·12 (Va)
Cadmium	.	.	.	.	1·8 (d 1 R)	1·96 (V and O)		1·97 (Va)
Lead	.	.	.	.	1·9 (d 1 R)	1·95 (V and O)		
Thallium	.	.	.	.		2·00 (V and O)		
Zinc	.	.	.	.	2·0 (d 1 R)			
Mercury	.	.	.	.	4 (W)	4·08 (C and B)		1·5 (G)
Antimony	.	.	.	.	0·7 (d 1 R)			
Bismuth	.	.	.	.	0·46 (d 1 R)	0·45 (V and O)		0·46 (Va)

9. The Thrust Exerted by Growing Crystals.

Reference has been made to effects produced in the crystallization of certain metals, which may be readily confused with changes of volume. A great many experiments were made by Duvernoy,† tending to show that many substances, ordinarily supposed to contract on solidifying, really expanded. Thus, an iron vessel provided with a neck was filled with molten lead, which contracted during cooling, but towards the close of the solidification the remaining liquid rose in the neck, indicating expansion.

These experiments were criticized in detail by Volger, ‡ who showed that Duvernoy's conclusions were incorrect. The greater part of the apparent expansion might be accounted for by the thrust exerted by the growing crystals. In the lead experiment, for example, crystals grew from the walls of the vessel inwards, pushing the liquid metal before them. As precautions were not taken to ensure a progressive solidification from the closed to the open end of the mould, the mass was closed at some distance below the neck, and cavities formed in the body of the solid metal. A spherical casting of lead always contains a central cavity. Hence the necessity, in dilatometric experiments, of allowing freezing to proceed

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* K. Borneman and G. von Rauschenplat, *Metallurgie*, 1912, vol. ix. pp. 473, 505.

† *Loc. cit.* See p. 94.

‡ G. H. O. Volger, *Poggendorff's Annalen*, 1854 [ii.], vol. xciii. pp. 66, 224.

very slowly from the closed end of the containing vessel onwards, so that liquid may be continually supplied, and the formation of a cavity avoided.

The difference between a true increase of volume and an apparent expansion due to the thrust exerted by growing crystals is well illustrated by the case of plaster of Paris. When a test-tube is partly filled with a paste of plaster and water, the mass sets with apparent expansion, and the tube is often burst. Nevertheless, the reaction

$$2CaSO_4, H_2O + 3H_2O = 2[CaSO_4, 2H_2O]$$
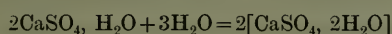
is accompanied by a *diminution* of volume of about 7 per cent. The force acting on the glass walls is a thrust due to the power of orientation of the crystals. The power possessed by growing crystals of gypsum, of pushing aside large masses of clay, was observed in volcanic deposits by Bunsen. * It is a factor of some importance in geology. Thus, crystals of pyrites may grow outwards, thrusting rock before them with considerable force, † and similar phenomena have been shown to occur in the formation of metallic veins. The evidence on this point has been recently summarized. ‡

The disintegration of earth by the growth of ice-crystals has been recorded by many observers. § || The columnar crystals may raise masses of earth vertically in the course of their growth, and it appears that the disruptive action of frost on rocks is probably due as much to thrust exerted in this way as to the actual expansion during freezing. This conclusion was emphasized by Volger, and receives further confirmation from the behaviour of crystallizing salts when absorbed by porous materials. Thus, porous tiles and bricks are disintegrated by soaking in a solution of sodium thiosulphate and allowing this to crystallize, although the crystallization of the salt takes place with diminution of volume.

* R. Bunsen, *Liebig's Annalen*, 1847, vol. lxii. p. 1.

† F. Pošepný, *Archiv für praktische Geologie*, 1880, vol. i. p. 289.

‡ W. Bornhardt, *Archiv für Lagerstättenforschung*, 1910, Heft ii.

§ James Thomson, *Collected Papers*, p. 269; observations made in 1864.

|| B. Schwalbe, *Verhandlungen der deutschen physikalischen Gesellschaft*, 1885, vol. iv. p. 26.

This process is employed in the testing of porous ceramic materials.*

The thrusting aside of impurities by the advancing tip of a growing crystal is easily observed under the microscope, and many examples are given by Lehmann. The measurement of the force exerted is not easy. In a single experiment, a crystal of alum, the area of which could not be accurately measured, was observed to exert a vertical lifting force of one kilogramme, when growing upwards in a flat-bottomed vessel.† The thrust measured in Chamberlain's experiments is, of course, the resultant of actual volume changes and of many individual thrusts varying in direction.

Effects of this kind may be expected to be most pronounced in anisotropic metals, but it is not confined to them. The metals which crystallize in the cubic system commonly exhibit a tendency to skeletal growth in the direction of a single axis, which may result in a thrust. The whole subject calls for further investigation.

It is not necessary to assume the existence of a separate "crystalline force." The ordinary cohesive forces in solids have, in crystals, vector properties, and act more strongly in certain directions than others. This is in fact implied in the idea of a crystal, and the phenomenon of crystal thrust is to be expected as a result of the vectorial character of cohesion.

Programme of Experimental Work.

The scheme proposed by Dr. Beilby included the preparation of a summary of the existing knowledge on the subject of the solidification of metals, and also an experimental investigation of some of the factors. Only the first of these objects has been dealt with, and that very briefly, in the present report. It is probable that many publications bearing on the subject have been overlooked; whilst many others, although consulted, have been omitted owing to considerations of space. An attempt has been made to include all relevant work in the

* J. W. Cobb, *Journal of the Society of Chemical Industry*, 1907, vol. xxvi. p. 390.

† G. F. Becker and A. L. Day, *Proceedings of the Washington Academy of Science*, 1905, vol. vii. p. 283.

preliminary survey; but, from the nature of the subject, it is almost impossible to make an exhaustive search. The discussion of the phenomena of crystallization from solid solution has been postponed to a later occasion.

One point which an examination of previous work has made clear is that more than one cellular structure may be present in a solid metal at the same time. This is clearly shown by some of Cartaud's photographs; and it is evident that some observers, seeking to explain the origin of the cellular structure, have confounded cells of different orders. One series of experiments now in hand is therefore directed to determining the relation between different cellular structures. For this purpose it has been found advisable not to confine the experiments to metals, but to include readily fusible salts and organic compounds, the use of which presents several advantages.

Another fact which has become strikingly evident is that very similar structures may arise from very different causes. Plane sections through a bees' honeycomb, a *Lithostrotion* coral, a cake of wax solidified in Dauzère's apparatus, a mass of columnar basalt, a benzene-water foam, and an over-annealed β-brass, are all very similar in appearance, being divided into approximately equal cells, tending towards a more or less hexagonal outline. Yet the origin of the hexagonal cells is very different in the cases quoted, the first two being the product of living organisms; the third, and probably also the fourth, being produced by mutually repelling convection currents; the fifth by surface tension; and the last, in all probability, by crystallization from independent centres or nuclei. The property common to all of them is a geometrical one, connected with the regular distribution of points in a plane or in space. Some writers who have sought to explain the structure of metals have fallen into the error of assuming community of origin where there is only similarity of arrangement, due to merely geometrical causes.

Preliminary experiments have shown that some of the effects recorded by previous observers are connected with the presence of a thin film of oxide at the surface of the metal. It is therefore proposed to use, as a standard of structure in

freely crystallized metals, buttons of metal which have been fused and allowed to solidify in a high vacuum. It should be possible in this way to obtain a structure which is fully representative of the process of crystallization of an undisturbed metal.

For metals of low melting-point, the method is also being adopted of observing the process of crystallization in a small mass of metal, melted on an electrically heated microscope stage, and covered by a thin cover-glass of transparent silica. In this way it is possible to compare the process in metals with that in salts and organic compounds.

Lastly, a series of experiments on volume changes is in progress, using silica dilatometers and fused salts as filling liquids. It is hoped that the results may be presented to the Committee at an early date.

DISCUSSION.

Sir HENRY ORAM, K.C.B., F.R.S. (President), said that he was very pleased to announce, on behalf of the Council, that the further experimental work indicated by Dr. Desch as being necessary would be able to be carried out owing to the generosity of Dr. Beilby. Dr. Beilby was deeply interested in this subject, and he had placed an adequate sum at the disposal of the Committee, which would ensure the continuance of the work. Dr. Desch had very kindly accepted the invitation of the Council to carry out the further experimental research required. He had read through the Report, and had been struck with the amount of work which Dr. Desch had performed. The number of authorities and papers which had been consulted was enormous, and represented a very considerable amount of time devoted by Dr. Desch to this important subject.

Dr. G. T. BEILBY, F.R.S. (Member of Council), said that he thought the first feeling the members must all have in reading Dr. Desch's Report was that the Committee had been extremely fortunate in securing Dr. Desch's co-operation. They must all, as scientific and practical people, recognize that it was only too easy to criticize. The critical attitude was a very easily assumed attitude, and criticism could be very cheap. In Dr. Desch had been found a worker who had not merely the critical attitude, but who possessed what was much more important, namely, the judicial attitude; and one felt that that judicial attitude was always to the fore in the Report. Possibly, as Dr. Desch proceeded with his work, he might have to become more enthusiastic on special views and theories than he had allowed himself to be up to the present time.

He was interested in what Dr. Desch had written in the final paragraph of the Report, namely : " Preliminary experiments have shown that some of the effects recorded by previous observers are connected with the presence of a thin film of oxide at the surface of the metal." In bringing the matter originally before the Institute, he (the speaker) had cited some experiments of his own performed upon globules of metal which had cooled in entire freedom from any attachments which would cause particular strains in cooling. This was done by fusing a globule at the end of a wire, and then examining the globule to find what the condition of crystallization in the globule was. At the May Lecture he had exhibited some photographs obtained in that way. Although the metal he had always preferred to use was gold, he was quite prepared to read into his experiments the suggestion of Dr. Desch's, that even in the gold globule, which had been melted in a clean gas flame, it was quite conceivable that some of the crystalline sacs which his (the speaker's) photographs showed existed—sacs of different orientation —might have had their origin in films formed on the wire before it ran into the globule form. Therefore, he was glad that Dr. Desch was now preparing to follow up that matter by experiment. He might suggest that, even apart from Dr. Desch's method of using a high

vacuum, it might be possible to obtain globules which were entirely free from internal films of oxidized material by mere subdivision of a molten mass of metal into globules.   If one were to drop mercury on a clean surface and then freeze the resulting globules one might have this condition, and it would be very interesting to see whether in that case the orientation was uniform throughout the globule—in other words, whether one crystal was produced, or many.

Professor A. K. HUNTINGTON, Assoc.R.S.M. (Past-President), considered that the Institute was very much to be congratulated on the First Beilby Report.   It was remarkably clear, and contained an enormous amount of information.   If he did not know Dr. Desch very well, he should have thought the Report must have taken an infinitely greater time to compose than probably it actually did.   Dr. Desch seemed to possess a most extraordinary facility for looking up and abstracting all sorts of papers ; he (the speaker) did not know anybody in any way equal to him in that direction, and he considered the Institute might congratulate itself in having such a man to draw up reports for it.

It came out very clearly from the Report that there were many ways of obtaining polygonal structures.   Some people seemed to have been carried too much away in one direction, losing sight of the fact that there were so many ways.   On page 76, Weber and Lehmann were referred to, and also a mixture of alcohol, gamboge, and water—a most horrible mixture, he should imagine, completely denaturized !   On several occasions when he had been suffering from an attack of influenza he had been brought back into his ordinary robust condition with the help of beef-tea.   The beef-tea, being served very hot in a bowl, and not in a soup plate, he had on several occasions noticed that the whole of the surface of the beef-tea was divided into very perfect hexagons, which were in active movement.   The flocculent matter which existed in that succulent product of the culinary art when well made was violently agitated and circulated in each hexagon in a perfectly definite way. Therefore it was possible, even in one's home, to be pursuing, by very ordinary means, most interesting scientific facts without going into the laboratory as Weber and Lehmann had done, and using comparatively complicated apparatus.   He did not consider that the beef-tea experiment had any direct bearing on the crystallization of metals.   Dr. Desch brought out the fact in his paper that the crystallization of metals was perpendicular to the bounding surfaces, whereas the sort of effect to which he (the speaker) had been referring were necessarily taking place vertically by means of convection currents.

On page 85 Dr. Desch brought up the question of the crystalline structure of metals and the difficulty of examining the crystals which formed a mass of metal.   The ordinary way, of course, was to polish and etch a surface and to examine the crystals and their orientation as shown on that surface.   It had come to his knowledge, without any significance of a practical or scientific character being attached to it in any way, that if a copper-zinc β-alloy containing about 2 per cent. of

aluminium was treated with mercury, the crystals composing the piece of metal would absolutely separate at their boundaries without—if, at any rate, a moderate time only was used—the crystals in any way being attacked. So that there were actually shown the contact surfaces of the crystals. It had occurred to him that that might prove of very great use in studying the structure of crystallites and their boundaries. He mentioned the fact because it might be of interest to others to follow it up as it was so exceedingly simple to carry out and gave what hitherto it had not been possible to obtain, namely, a parting of the crystals at their boundaries without any damage. It raised all sorts of questions. For instance, what was the meaning of it? How had the crystal boundaries been acted upon by the mercury? Was something existing there in the nature of a cement which had been dissolved out, or was it due to capillary action? It would be worth while to analyse the mercury when it had passed through the boundaries, and to determine the amount of mercury retained by them.

Dr. WALTER ROSENHAIN, F.R.S. (Member of Council), said that he desired first of all to add his quota to the volume of congratulation which was flowing towards Dr. Desch. It was extremely well deserved, as the Report was one of the most interesting documents of its kind that he had ever read. It would prove for some time to come a mine of information, and, like some of Dr. Desch's other publications, a constant source of comfort to the man in search of a reference. Whenever he (the speaker) required a reference to the literature of metallography, he turned to Dr. Desch's books and papers to find it, feeling tolerably certain that any paper he had ever read would be referred to there, and probably a good many more.

Dr. Beilby had characterized the Report in two words by referring to Dr. Desch's judicial attitude. One could read between the lines of that judicial attitude towards the end of the Report. It was like a judge's summing up. After all, the judge had sometimes to pass sentence also, and there was very little doubt as to what the sentence on the Quincke hypothesis would be on the evidence as far as it went at present. He considered that a judgment adverse to that hypothesis would only confirm the opinion of every metallographer who had considered the matter. It was all very well to say that there were many ways of forming cellular structures, but it had yet to be proved that the structure of a metal was really cellular, except in the purely geometrical sense. The real distinction between the various forms of so-called cellular structure was in their mode of origin, and in the case of a great many metals that mode of origin could be clearly traced in the structure of the resulting mass. Taking, for instance, a solid solution which had been crystallized with moderate rapidity and in which the dendritic cores were well developed, there was a "cellular structure" indicated by the crystal boundaries, but within each of those crystal boundaries the history of the crystal was written in the outlines of the dendritic core, which, if it had any meaning at all, showed the real mode of formation of that structure. It showed that it had been formed by the growth of the dendrite

from a centre, and not by the subsequent internal crystallization of a previously-formed sac. He could see no way of accounting for the dendritic cores of solid solutions by supposing that their structure had been governed by the previous existence of cellular envelopes in the liquid before crystallization began. It was obvious that there was only one centre inside each cell, and that growth had taken place outwards from that centre. He considered that fact alone almost sufficient to dispose of the foam-cell hypothesis.

There were a great many matters in Dr. Desch's Report which gave food for interesting discussion, but he would not attempt to touch on many of them. He had to make one or two points of minor criticism on some matters, which Dr. Desch might consider. For instance, on page 59, line 18, Dr. Desch spoke of "the smaller power of orientation at high temperatures possessed by silicates." He (the speaker) desired to ask what was meant by the "smaller power of orientation." Was there such a thing as "power of orientation" at all? Was not that a sort of reversion to an old idea, something like that of "vital force" and other forces of that kind of which nothing was known? He should feel inclined to say that the real explanation of the difference between silicates and metals in regard to the facility of undercooling lay in differences in the linear velocities of crystallization. That was a physical quantity which had a definite meaning, whereas the "power of orientation," he ventured to think, was something to which no very definite meaning attached at the moment.

Then, on page 61, Dr. Desch referred to the difficulty of studying isolated crystals of the majority of metals. There were many other ways besides those mentioned by Dr. Desch in which isolated crystals of metals could be and had been studied. For instance, Dr. Desch referred chiefly to the study of the crystals of native copper and gold, but there were other ways of obtaining metals in isolated crystals. Dr. Desch spoke of bismuth being obtained in beautiful crystals when the crust of an ingot was broken. He (the speaker) had in his possession, by the courtesy of Messrs. Cookson, a very fine piece of antimony which exhibited exactly that same feature. A great many of his friends thought it was bismuth when they first saw it. He had succeeded in producing crystallites of a great many other metals by exactly the same process. The copper-aluminium compound $CuAl_2$ was well known as an example, and there were a good many others besides. Further, Osmond and Cartaud produced complete crystals of iron at various temperatures by the reduction of ferric chloride in hydrogen, and they were able to examine and even to measure those crystals with considerable success. Recently he himself had produced crystals of zinc by sublimation, which were so large that they could be handled without the use of the microscope, and had been employed by Messrs. Kaye and Ewen in some of their researches. Therefore he considered the field for the examination of isolated crystals was rather larger than Dr. Desch's remarks would suggest. He was saying that not in any criticism of Dr. Desch, but because

he wanted to be sure that anyone referring to the Report would not be discouraged from an attack on the geometrical crystals of metals by the remarks of Dr. Desch.

He desired next to refer to a point on which he had addressed the Institute previously at some length, namely, the influence of surface tension on crystals. He did not desire to go into the matter very fully, but he did want to say one thing, namely, that surface tension, after all, exerted forces whose one and only reason for exist-ence was the tendency to diminish the total surface area. That tendency, it appeared to him, could result, and, in fact, in very small crystals did result, only in an approximation to the spherical form. That approximation was almost complete—he thought quite complete—if the crystal was small enough. Then, after that, there was a ten-dency towards the formation of angles, which ultimately became fully developed. But how it was possible to ascribe the formation of a dendrite, such as that sketched by Dr. Desch in his paper, to the action of surface tension, he failed to see. There, one had a structure which, so far from having a minimum surface area, tended at any rate towards a maximum surface area ; and the effect of surface tension could only, he thought, be traced in the rounding, which did occur in some cases, in the angles and edges of that dendrite.

Dr. Desch frequently referred to the influence of surface tension in affecting the re-crystallization of metals. First of all it had to be proved that there was surface tension between the crystals of a solid metal. That was entirely an assumption at the present time which had yet to be proved, but even if it were admitted, what would be the result ? If a crystal was strained it was elongated, and if surface tension came into play its tendency would be to make the crystal revert to its original equi-axed form when annealing took place ; that return would produce a diminution of surface area. That, however, was *not* what happened ; on annealing, the elongated crystal first breaks up into a multitude of small crystals, having a total surface area enormously greater than the elongated crystal itself. How could surface tension play a controlling part in that process ?

The points he had mentioned had been suggested to him by the reading of the Report. There were a great many others, and he was sure that the members would all value the Report more highly as time went on, when they could digest its contents and make use of its information more fully.

Dr. J. E. STEAD, F.R.S. (Middlesbrough), said that he agreed entirely with the remarks of previous speakers who had complimented Dr. Desch on his admirable communication. One was impressed by the fact that the author was an indefatigable worker, judging by the immense amount of foreign and English literature he had referred to.

He (Dr. Stead) had on more than one occasion referred to the way antimony crystallized.

Quite recently he had had proof that very pure 4 per cent. silicon steel, when solidifying, crystallized in a manner very similar to anti-

mony. When the metal commenced to freeze against the cold sides
of the mould a multitude of crystals of varying orientation were first
formed, but it was only those which had cleavages parallel with the
flat side of the mould that survived. The reason for this appeared
to be that the crystals, arranged as described, developed vertically to
the surface of the mould, whereas the others grew at varying angles, and
therefore at less speed in a vertical direction. At a distance of about 10
mm. from the surface all but the vertical-growing crystals disappeared.

On breaking up the metal when it was cold, the fracture had the
appearance of the basaltic column of the Giant's Causeway, the flat
faces being, however, cleavages, and not intercrystalline junctions between
the crystals. When broken through the columnar crystals, the fractures
of the cleavages were at right angles to the vertical columns and parallel
to the sides of the mould.

Dr. DESCH, in reply, thanked the speakers for their kind apprecia-
tion of the Report, which did not claim to be anything more than a
collection of facts bearing on the subject. Dr. Beilby's remarks had
been very valuable, and he would certainly bear in mind his sugges-
tions as to the possible means of getting masses of metal free from
external complicating influences. He had been also much interested
in Professor Huntington's account of his very simple method of iso-
lating crystal grains, which was probably quite widely applicable. It
would be very interesting to see the results of microscopical examination
of those grains. Professor Huntington had referred to the hexagonal
partitioning which was to be seen in beef-tea. That hexagonal par-
titioning was first noticed by Professor James Thomson, about thirty
years ago, in a tub of soapsuds. Professor James Thomson, being one
of those men to whom no fact was trivial, at once sought for and
found an explanation. His work, however, was completely overlooked,
and the fact was rediscovered a few years ago by Bénard in France,
and since then had attracted attention. On reading Professor Thomson's
paper he (Dr. Desch) at once remembered that he had seen the structure
referred to in beef-tea. The effect was quite beautifully produced, but
he supposed hundreds of people must have seen the structure, and yet it
had never occurred to them, as it had never occurred to himself, to
inquire why the particles arranged themselves in hexagons. He had
lately come across another form of partitioning in liquids which was
not vertical, and was not due to convection currents, but was actually
a horizontal partitioning. It was very curious that those structures
were set up in liquids. However, he did not think that that particular
one occurred in metals, but he was making some experiments on the
subject which he would communicate to the Institute in due course.

Dr. Rosenhain had raised a good many points, all very interesting
in themselves, and as to some of which there was a possibility of a good
deal of difference of opinion. He (Dr. Desch) did not desire to admit
that he had condemned Quincke's hypothesis in advance; he hoped
still to keep an open mind. Professor Quincke's suggestion was based
on an enormous amount of experimental work, and he (Dr. Desch)

would not like to say that it could be dismissed at once. He could quite agree that the crystal grains bore, in their internal structure, evidence of the way in which they were formed; they certainly did crystallize from centres, but the history of the crystal grain perhaps began a little earlier than that. Professor Tammann had worked out a mathematical relation between the number of centres and the degree of undercooling, but why did those centres arise in that particular way? Was it merely a question which could be calculated by the calculus of probabilities? Was it merely a chance distribution, or was there something else governing it? Such a hypothesis as that of Professor Quincke suggested a reason for a partitioning taking place before crystallization began from the centres. So with Bénard's work on the convection cells. It appeared that sometimes, as the liquid cooled, on changing to the solid state, the arrangement of the crystal centres was determined by the arrangement of convection cells, and each convection cell became a crystal grain; in fact, with some masses of wax one could always break the solid mass into little hexagonal prisms, each of which represented an original convection cell.

He still thought it was very difficult indeed to obtain isolated crystals —he meant crystals of which one could study the crystallographic pro- perties. Even masses of bismuth or of antimony which looked so beau- tiful were quite useless to a crystallographer, as they were merely skeleton forms. Professor Pope, one of the leading crystallographers at the present time, told him a short time ago that there was no metal, except those that crystallized in the regular system (in which one had only to calculate the crystallographic properties), of which the crystallo- graphic measurements were known with accuracy. Gold and copper belonged to the regular system, and there was no need to make measure- ments; but of the anisotropic metals practically no accurate measure- ments existed.

As to the part played by surface tension, he agreed there was room for discussion. By power of orientation he did not wish to imply any- thing at all metaphysical; he merely meant that certain substances formed skeletons much better than other substances. For instance, antimony, crystallizing with other substances, quite readily formed sharp dendrites. Taking antimony alloyed with 20 per cent. of copper, there were dendrites which were perfectly sharp, and even in the eutectic it would be found that the antimony particles were as sharp as in isolated crystals of antimony. That was not so with copper or silver. With these metals the dendrites were always rounded when they were alloyed with other substances.

He had been very much interested in Dr. Stead's remarks as to vertical crystallization. He quite agreed that Dr. Stead was correct in saying that it was a case of the survival of the fittest, and that the perpendicular crystals had an advantage over the others. With regard to the columnar structure in basalt, as in the Giant's Causeway, there was the difference that the columns were not crystals. Each of those columns was made up of an enormous quantity of minute crystals with all kinds of orientation, and he believed now that the columnar structure was Bénard's

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convection structure. The columns in basalt were originally vertical. He (the speaker) thought that it would be seen that in the original sheet of molten lava convection currents were set up, and crystallization then took place within the cells. The convection currents would explain that structure of igneous rocks; but he did not think they would go far to explain cast metals, except when cast in thin sheets.

COMMUNICATIONS.

Professor GEORG QUINCKE (Heidelberg) wrote that it was not correct (p. 69) that Brillouin in 1898 first explained the behaviour of metals on deformation by thin layers of an amorphous cement. The writer,* in 1868, explained the difference of strength of hard-drawn and annealed wires by such thin layers.

It was not the case (p. 74) that the writer explained the hardening of metals in "a somewhat forced manner." Tresca's experiments and technical experience showed that metals flowed like highly viscous liquids, consequently they exhibited surface tension at their contact with air and other substances. The surface of mercury and other liquids is rendered immobile by films of foreign matter,† and metals throughout which films of foreign matter are distributed must therefore be harder and less mobile than annealed metals without such films. From the experiments of Knut Ångström,‡ the molecular pressure of water on absorbed gases was seen to be about 2500 to 3000 atmospheres. A pressure of this order must also exist in the invisible foam walls of fused and rapidly-cooled carburized iron.§ The carbon must then, from Moissan's experiments,‖ be dissolved as diamond, and on rapid cooling must solidify as diamond.

That the walls of foam-cells met at angles other than 120° and 90° was explained by the presence of invisible films of foreign matter, which collected at the surface of the cell walls and lessened their surface tension.

As even the purest vacuum-distilled metals and other substances showed more foam-cells the more rapidly they were cooled, the writer assumed that on solidification or on the transformation of a high temperature into a low temperature modification, a small quantity of the material stable at a high temperature remained and behaved as a foreign substance. Its quantity was greater the more rapid the cooling.¶ This assumption also explained the varying values (p. 93) for the density of the liquid and solid metals, and for the expansion or contraction at the

* *Berliner Monatsberichte*, February 27, 1868, p. 139.
† G. Quincke, *Poggendorff's Annalen*, 1870, vol. cxxxix. p. 71; *Pflüger's Archiv*, 1879, vol. xix. p. 141; *Annalen der Physik*, 1888, vol. xxxv. p. 589.
‡ *Ibid.*, 1882, vol. xv. p. 351.
§ *International Journal of Metallography*, 1912, vol. iii. p. 95.
‖ *Annales de Chimie*, 1896 [vii.], vol. viii. p. 558.
¶ *Proceedings of the Royal Society*, 1906, vol. lxxviii. *A*, p. 87.

change of state, which had been obtained by experienced observers, using different rates of cooling.*

The writer's views on liquid crystals and myelin forms, referred to on pp. 81 and 87, were opposed to those of Lehmann.

Referring to the statements recorded on p. 76, he (Professor Quincke) desired to say that if a second liquid spread out on the surface of a liquid the original surface tension were thereby lowered, as was first shown by himself.† Vortex movements were thus set up, which deformed the surface in different ways, according to the varying velocity of spreading. The operation became periodic or apparently continuous.‡ Such vortices explained the peculiar movements observed by Weber and the so-called convection currents of Bénard and the formation of hexagonal prismatic cells in thin layers of liquid warmed from below. The ascending filaments of warm liquid collected at the warmest, most rapidly ascending columns, reached the colder surface with the higher-surface tension, and spread out over it. Through the vortex thus set up the centre was depressed. The prismatic cells were formed by the meeting of opposite currents from neighbouring centres. In Lehmann's *Molekularphysik*, vol. i. p. 271, vortices due to the spreading out of liquid were described as " contact movements," but without reference to the writer.

Similar hexagonal prismatic cells were formed by neighbouring sphæro-crystals when radial tubes of oily liquid arranged themselves normally to the central nucleus.§ The radial tubes might have expansions and contractions or break up into chains of drops.

Fused sulphur, referred to on p. 65, did not first separate as globules and then as chains, as stated by Vogelsang and Brame. Tubes of oily foreign matter filled with liquid sulphur were first formed, which then broke up into connected or disconnected rows of drops.‖

Liquids, referred to on p. 88, were more readily undercooled, the smaller their mass and the greater their surface.¶

When molten metal or ice was cooled (*vide* pp. 64 and 65), there existed between the solid layers of frozen liquid A with little impurity, liquid layers of B with more impurity, which solidified subsequently. The impurities might be gases or allotropic modifications of the metal or water. The less impure layers were thicker ; the less impurity the liquid contained and the more slowly it solidified. The periodic separation of the liquids A and B in the solidification of metals was thus explained. The reason why the two liquids B and A remained side by side without mixing was unknown, as was the reason for gravitation. Both were facts. In general, the liquids A and B contained the same constituents,

* *International Journal of Metallography*, 1912, vol. iii. p. 89.

† *Poggendorff's Annalen*, 1870, vol. cxxxix. p. 28.

‡ *Pflüger's Archiv*, 1879, vol. xix. p. 129 ; *Annalen der Physik*, 1888, vol. xxxv. p. 601, and Plate vii. Fig. 2.

§ *Annalen der Physik*, 1903, vol. vii. p. 734.

‖ *Ibid.*, 1908 [iv.], vol. xxvi. pp. 657, 694.

¶ H. C. Sorby, *Philosophical Magazine*, 1859 [iv.], vol. xviii. p. 105 ; L. Dufour, *Poggendorff's Annalen*, 1861, vol. cxiv. p. 534 ; G. Quincke, *International Journal of Metallography*, 1912, vol. iii. pp. 28, 91.

but in different concentrations. Unfortunately there was no method known of separating the foam-wall liquid B from the liquid contents A, or to determine their composition by chemical analysis. This could not be determined theoretically by the principle of energy, as the quantity of foreign matter (allotropic modification) depended on the rate of cooling.

The objection that the writer's investigations yielded only qualitative and not quantitative evidence for the foam structure of metals was unfounded. The determinations, indeed, did not yield figures, but the influence of changes in the quantity of foreign matter on the number and form of the foam-cells at different rates of cooling had been shown.*

The formation and shape of crystallites, crystal skeletons, dendrites, &c., referred to on pp. 61, 74, and 85, were mainly dependent on the thickness of the solidifying layers of liquid and on the velocity of solidification, as was shown by his (Professor Quincke's) experiments of 1903–1904.† All possible forms of metallic salt vegetations ‡ and foam-cells of the types I. and II. might present themselves.

Dr. T. K. Rose (London) wrote that Dr. Desch's summary of the existing state of knowledge was so excellent that he considered it almost beyond either praise or criticism. Nevertheless, he hoped that Dr. Desch would not omit from his final reports adequate consideration of what was often called recrystallization on annealing. Changes of structure took place after solidification in all cases, although no doubt they could be reduced to a minimum by rapid cooling. It followed that it was necessary to bear in mind the modifications due to these changes, and they could best be made clear by studying the recrystallization which occurred when the solid metals were reheated.

Mr. Sydney W. Smith, B.Sc., Assoc.R.S.M. (London), wrote with regard to the methods which were available for the determination of the fluid densities of metals referred to by Dr. Desch on pages 93–101 of his Report, that it might be of interest to record a method by which he (Mr. Smith) had succeeded in making some determinations of this kind four years ago (1910).

The method adopted was an application of the principle of Matthiessen's method of determining the coefficient of expansion of a liquid by weighing a " sinker " in it at different temperatures. The " sinker " used consisted of a quartz bulb filled with metal of a higher density than that to be examined. In the experiments referred to both gold and silver were used for this purpose.

The bulb, after filling, was exhausted and sealed off, and then suspended by a fine wire from the beam of a balance and completely immersed in the molten metal. The temperature was recorded autographically as each weighing was made. In this way determinations of the fluid den-

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* G. Quincke, *Annalen der Physik*, 1905 [iv.], vol. xviii. p. 38.
† *Ibid.*, 1902 [iv.], vol. ix. pp. 819 *seq.*, Figs. 93, 94, p. 805, Fig. 87 ; *ibid.*, 1904 [iv.], vol. xiii. pp. 71 *seq.*, Figs. 175 a, b, c, 179–181, 182.
‡ *Ibid.*, 1902 [iv.], vol. vii. pp. 631 *seq.*

sities of lead and of bismuth were made over a considerable range of temperature; those in the case of bismuth confirming, of course, its greater density in the liquid state. It was hoped to submit the results of this work to the Institute shortly.

This method would be seen to bear a close analogy to the admirable work recently published by MM. Pascal and Jouniaux.*

Some discussion had arisen on the remarks of the author of the Report concerning the effect of films of oxide on the behaviour of metals preceding or at solidification. In a paper on " The Behaviour of Tellurium in Assaying " † he (Mr. Smith) had drawn attention to the striking part which films of fused litharge might play when certain alloys were melted on a cupel.

It was shown that molten alloys of lead with gold (or silver) and tellurium which, in a reducing atmosphere, remained in the spheroidal state on a " dry " cupel, were immediately absorbed by a cupel which had been previously " wetted " by cupelling a little lead upon it.

The cohesion of the alloy, already weakened by the presence of tellurium, broke down to such an extent under these conditions that the metal spread itself out over the cupel and was completely absorbed.

The same effect was produced by admitting sufficient air to form a film of litharge on a molten button of an alloy of lead, gold (or silver), and tellurium. The spheroidal surface at once flattened out, and the metal sank into the cupel. This was also shown to occur with alloys of gold (or silver) and tellurium in the absence of lead if the temperature were sufficiently high to fuse the tellurium dioxide which was formed.

Further work in this direction was in progress.

Dr. Desch wrote in reply to Professor Quincke's interesting communication, that a full discussion of the points raised must be postponed to a later report. There was a difference between the explanation of the hardening of metals given by Professor Quincke in 1868 and that which was now under discussion. The early explanation was based entirely on the phenomena of surface tension, and the films enclosing the crystal grains were therefore assumed to be of only molecular thickness. Professor Brillouin, however, assumed the presence of relatively thick layers, and Dr. Beilby's amorphous layers were also of appreciable thickness. Dr. Rosenhain, in expounding the hypothesis of crystal structure associated with his name, had insisted that a layer of molecular thickness was insufficient to produce the observed effects, and that other factors than surface tension were at work. The writer was in agreement with Professor Quincke that surface tension played a very important part in the phenomena under discussion, which had been insufficiently appreciated.

The writer had mentioned two main difficulties in the way of accepting Professor Quincke's hypothesis, namely, the irreversible character of the diffusion process, whilst the foam-cell hypothesis presupposed segregation in a homogeneous liquid, and the absence of any quantitative treatment.

* *Comptes Rendus*, January 1914, No. 158, pp. 414–416.
† *Transactions of the Institute of Mining and Metallurgy*, vol. xvii. (1907–1908), pp. 453–476.

The first difficulty was perhaps not insurmountable. The writer could not accept the view that the segregation was a fact, and must be accepted as such, like the fact of gravitation, notwithstanding our inability to conceive the manner in which it acted. On the contrary, it was the experimental evidence for the supposed fact which the writer was unable to regard as fully convincing. Should it be demonstrated, an explanation of its apparent contradiction with thermo-dynamical laws might possibly be found in some facts connected with the physics of colloids.

The second difficulty had not been met. The mathematical theory of crystal structure was now almost perfect, and the foam-cell hypothesis failed to account for the extraordinary regularity of arrangement which prevailed in crystals. There seemed to be no way in which that hypothesis could, in its present form, be applied quantitatively. The writer wished to repeat that he had not expressed an opinion as to the truth of the hypothesis, but had merely presented an account of the principal facts which fell to be considered in forming any conclusion. He hoped to investigate experimentally several questions which had presented themselves in the course of a study of the extensive researches continued by Professor Quincke over so many years. In the meantime, he was glad that Professor Quincke had added to the value of the discussion by his interesting notes and references.

The point mentioned by Dr. Rose would not be overlooked. Whilst it was thought advisable to confine the first report to the subject of crystallization from the liquid state, information regarding crystallization from solid solution had also been collected and was in course of classification.

Mr. Smith's observations on cupellation were interesting, and would be noted. The method of determining fluid densities employed by him was no doubt susceptible of great accuracy, but it might be pointed out that it was subject to one source of error which was difficult to eliminate, namely, the adhesion of the surface film of metal to the suspending thread. In conclusion, the writer desired again to thank those gentlemen who had taken part in the discussion for their kind expressions.

MUNTZ METAL:

THE CORRELATION OF COMPOSITION, STRUCTURE, HEAT TREATMENT, MECHANICAL PROPERTIES, &c.*

By J. E. STEAD, D.Sc., D.Met., F.R.S., and H. G. A. STEDMAN.

PART I.

ALTHOUGH a great amount of general work has been done on brasses, there is still necessity for more.

As the structure of Muntz metal varies according to the heat treatment and rate of cooling to which it has been subjected, we decided on making trials to correlate the composition, microstructure, heat treatment, and physical properties of metal containing about 60 per cent. copper and 40 per cent. zinc.

Our scheme was to heat duplicate series of the metal of determined composition for 48 hours at temperatures between 470° C. and 860° C., allowing one set of bars to cool in the air, to quench the other set in cold water, and then to examine them afterwards.

After our work was completed and the paper written, we found that Dr. G. D. Bengough and Mr. O. F. Hudson had previously published a most elaborate research on the heat treatment of Muntz metal, and, in justice to these gentlemen, we introduce a short review of their premier research. The paper was published in the *Journal of the Society of Chemical Industry*, January 31, 1908.

It is impossible to do justice in a short review to their very careful work, and we must strongly advise all those who are interested in brasses to refer to the original. The Muntz metal used contained :—

								Per Cent.
Copper	.	.	.	.	.	.	.	60·43
Zinc	.	.	.	.	.	.	.	39·21
Lead	.	.	.	.	.	.	.	0·33
Iron	.	.	.	.	.	.	.	0·08
Tin	.	.	.	.	.	.	.	0·03
Bismuth	.	.	.	.	.	.	.	0·01
								100·09

* Read at Annual General Meeting, London, March 18, 1914.

The correlated temperatures of heating and the mechanical properties are summarized below.

The cast bars from 3-inch moulds, whilst still hot, were rolled to $1\frac{3}{4}$ inch diameter at a dull red heat and finished at about $650°$ C.   These bars were reheated and again reduced by rolling, and after cooling were pickled and cold rolled to $\frac{3}{4}$ inch diameter.   The bars were turned to size for tensile testing 2 inches by $\frac{1}{2}$ inch.   Pieces were cut, notched, and tested for impact resistance.   The results of testing were as follows, namely :—

	As Cast.	As Rolled.
Maximum strength in tons per square inch .	23·2	29·8
Elongation in 2 inches	18·5 per cent.	37·1 per cent.
Impact resistance	3·9 lbs.	5·3 lbs.

The mechanical properties of the annealed metals were as follows, namely :—

Temperature, Degrees C.	Number of Bar.	Time.	Tensile Strength Tons per Sq. Inch.	Elongation per Cent.
As rolled	1. Slowly cooled	...	30·2	37·7
As cast	1. Air slowly cooled	...	23·4	17·1
310	2. Slowly cooled	7 hours	28·6	43·0
335	16. ,,	7 days	27·4	45·1
400	12. ,,	4 hours	28·1	46·3
410	15. ,,	7 ,,	27·4	48·0
450	20. Quenched	2 days	24·8	45·7
470	17. Slowly cooled	$\frac{1}{2}$ hour	28·0	44·4
490	30. ,,	7 hours	26·1	56·0
540	21. ,,	7 ,,	24·4	57·7
590	13. Quenched	7 ,,	26·4	45·7
	14. Slowly cooled	7 ,,	23·8	52·5
605	06. ,,	7 ,,	23·3	53·3
650	25. ,,	$\frac{1}{2}$ hour	25·1	48·0
685	23. ,,	7 hours	23·5	53·5
690	03. Quenched	$\frac{1}{2}$ hour	26·15	14·0
	50. ,,	4 hours	23·76	10·0
	60. ,,	7 ,,	26·55	14·0
	05. Slowly cooled	7 ,,	26·00	45·0
765	8. ,,	$\frac{1}{2}$ hour	26·5	54·9
	9. ,,	4 hours	25·8	56·5
795	26. ,,	7 ,,	23·4	44·0
820	4. ,,	4 ,,	24·1	55·7
	28. ,,	$\frac{1}{2}$ hour	24·11	52·0
840	7. Quenched	$\frac{1}{2}$ hour	25·4	12·0

The authors show by their micrographs that heating for a week at $335°$ C. causes a great diminution of β, and that even heating at $450°$ C. for two days also results in the absorption of β by α.

The bar quenched after heating at $690°$ C. for seven days consists of cells of β surrounded by α—a structural arrangement which fully accounts for the low elongation of 14 per cent.

Summarizing their results—in the seven-hours' annealing the tensile strength falls gradually with increasing temperature up to a little above $600°$ C., but after this the fall is slight.

In the half-hour annealings the fall of tenacity is more gradual—rather rapid at first, but less rapid as the temperature rises above $600°$ C.

The elongation in the seven-hour annealings rises rapidly from 37 per cent. up to about 56 per cent. at $500°$ C., then rapidly falls to 45 per cent. after heating to $690°$ C., and rises again to 56 per cent. after heating to $765°$ C.

In the half-hour annealings the elongation rises steadily until a maximum is reached at about $765°$ C., after which it falls rapidly.

The authors quote the results of Lewis (*Journal of the Society of Chemical Industry*, 1903, 12), who found that the heating of Muntz metal for thirty hours resulted in complete disappearance of β, leaving pure α.

The second part of their research, published in July 1908, gives information about the mechanical and other properties of Muntz metal, and the manner in which it fractures under tensile and impact stresses.

As will presently be shown, our results confirm in many respects those of Bengough and Hudson, and as the latter were obtained on bars heated for a much shorter time they are more valuable from a practical point of view than ours. It is, however, remarkable that whilst the above-mentioned authors obtain the weakest bar by a seven-hours' heating and quenching from $700°$ C., our weakest material was obtained by heating for forty-eight hours at about $770°$ C.

Mr. F. Tomlinson of Messrs. The Broughton Copper Company, Limited, Manchester, most kindly supplied us with bars of brass in the form of cold-drawn round bars, $\frac{1}{2}$ inch in diameter.

The apparatus for heating the metal was supplied by the Cambridge Scientific Instrument Company, Cambridge, and consisted of a resistance tube electric furnace and a Whipple pyrometer.

The bars in duplicate were placed in the centre of the furnace and the pyrometer tube placed over them. When in position the open ends of the furnace were closed by loose asbestos.

Soon after commencing the experiments it was found impossible to maintain a constant degree of heat owing to changes in the room temperature. Consequently there was considerable variation during the 48 hours' heating in the furnace, amounting to between 17° and 50° C. The structure, however, varied proportionately to the mean temperature, and, our object being to correlate microstructure and mechanical properties, the bars, after heating over ranges instead of at fixed temperatures, answered the purpose.

Two bars were heated at the same time in each trial: one was quenched as soon as removed from the furnace, and the other was allowed to cool in the air. The bars most highly heated cooled down to below 400° C. in ten minutes.

The following table gives a record of the temperature:—

No.	Maximum, Degrees C.	Minimum, Degrees C.	Mean, Degrees C.	Range, Degrees C.
1	495	462	475	33
2	580	556	565	24
3	685	665	675	20
4	742	715	720	27
5	757	740	749	17
6	783	765	773	18
7	835	785	812	50
8	845	820	833	25
9	880	846	860	34

As will be shown in Part II. on the microstructure, the β constituent of the bar heated to about 475° C. was apparently in less proportion than was present in the 1—9 series. It was decided to heat other bars at a much lower temperature for a longer time, to determine whether it was possible to effect the complete absorption of the β constituent. Having found a heated flue at the Middlesbrough Gas Works, where the

temperature varied between 430° C. and 500° C., an iron pipe closed at one end was inserted in the flue; the bars of brass were placed in it, and were allowed to remain there for three months. Strips of zinc were also introduced, and when the specimens were removed it was found that the bar nearest the outer wall of the flue had not been heated to above 430° C., for only the inner end of the zinc strip had melted.

In order to determine the effect of still lower temperatures another bar was put into a superheater at one of the Cleveland & Durham Power Co.'s stations operating at 270° C., and kept there for 984 hours.

MECHANICAL PROPERTIES.

The bars were tested by the Sheffield Testing Works, Limited, Blonk Street, Sheffield, with results shown on p. 125.

HARDNESS TESTS.

All the specimens were also tested by the Brinell method, using a 10-millimetre ball and a pressure of 500 kilos.

By dividing the average tenacity by the average hardness numbers a ratio factor of 0·365 for air-cooled brass was obtained, which is very useful, for by multiplying the hardness numbers by this factor the approximate breaking load is obtained.

The actual and calculated tenacities, together with the Brinell number, are given in the following table :—

Description.	Quenched.			Air-Cooled.		
	1	**2**	**3**	**1**	**2**	**3**
A as received .	...	...	...	26·18	...	...
1 to 9 as received .	...	...	...	39·10	...	...
A	...	...	...	25·85	...	...
B	...	...	...	22·90	...	...
1	26·04	74	26·6	25·60	70	25·5
2	25·91	73	27·0	25·11	65	23·7
3	28·67	83	30·3	26·64	67	24·4
4	27·40	89	33·5	24·48	67	24·4
5	28·73	93	33·9	26·38	70	25·5
6	23·20	100	36·5	25·00	70	25·5
7	29·53	100	36·5	25·50	70	25·5
8	29·38	100	36·5	25·55	70	25·5
9	27·22	93	33·9	24·50	70	25·5

Column 1 gives the determined tenacity in tons per square inch, column 2 the determined Brinell hardness number, and column 3 the tenacity calculated from the hardness number and the factor already mentioned, namely, 0·365.

It will be observed that while the hardness of the quenched specimens rises with the temperature of quenching, the calculated tenacity is too high.

The appearance of the broken test-pieces is shown in Figs. 1 and 2.

The surfaces of the normal cold-drawn piece of brass and Nos. 1 to 3 were smooth. No. 4 was crinkled on the surface. No. 5 was very uneven, and, owing to the peculiar orientation of the crystals, the test-piece had during extension become elliptical in section—6·5 millimetres through the longer axis and 5·4 millimetres through the short axis. The length of some of the crystals could be traced on the surface, and varied between half and one inch.

No. 6 test-piece, quenched in water, owing to the small extension, was smooth on the surface, but the fracture consisted of several terminations of very large crystals which had evidently not been strongly held together, or which had envelopes surrounding them of a weaker substance than their mass. The test-piece of No. 6, cooled in air, had a crinkled surface, due to the presence of large crystals which flowed unequally during the extension in the testing machine.

No. 7 and 8 were less crinkled on their surfaces than Nos. 4 and 5, and Nos. and 9 were oval in section—6·7 millimetres by 5·7 millimetres and 6·5 millimetres by 5·7 millimetres respectively.

With the exception of No. 6 all the fractures were fibrous.

" A." The bar heated for three months at about 430° C. broke with a fibrous fracture, and the surface was smooth.

" B." The bar subjected to the influence of superheated steam also yielded a fibrous fracture.

The result of heating upon the physical properties of the metal is most marked.

In general terms the effect of heating followed by quenching, as compared with heating followed by cooling in air, is to

Mark.	Heat Treatment.		Quenched in Water.				Cooled in Air.			
	Tempera-ture.	Duration of Heating.	Yield Stress. Tons per Sq. Inch.	Maximum Stress. Tons per Sq. Inch.	Elongation in 1 Inch. Per Cent.	Reduction of Area. Per Cent.	Yield Stress. Tons per Sq. Inch.	Maximum Stress. Tons per Sq. Inch.	Elongation in 1 Inch. Per Cent.	Reduction of Area. Per Cent.
Normal bar of A and B	…	…	…	…	…	…	15·24	22·18	44	54
A	270	984 hours	…	…	…	…	13·76	25·85	54	63
B	430	3 months	…	…	…	…	11·52	22·9	56	63·4
Hard drawn	…	…	…	…	…	…	36·79	39·10	19	54
1	475	48 hours	15·79	26·04	45	66·2	15·07	25·6	50	65·6
2	565	,,	15·15	25·91	41	58·8	13·56	25·11	51	63·1
3	675	,,	14·64	28·67	38	43·8	13·41	26·64	47	58·8
4	720	,,	15·89	27·40	23	37·8	12·27	24·48	40	48·6
5	749	,,	19·67	28·73	20	32·6	14·42	26·38	42	43·8
6	773	,,	20·47	23·26	10	26·6	13·62	25·00	38	43·8
7	812	,,	19·33	29·53	25	26·0	13·08	25·50	48	53·9
8	833	,,	19·62	29·38	26	37·8	12·82	25·55	45	48·6
9	860	,,	18·45	27·22	30	32·1	14·93	24·50	48	58·2

The bars for A and B were different from those of Nos. 1 to 9.

FIG. 1.
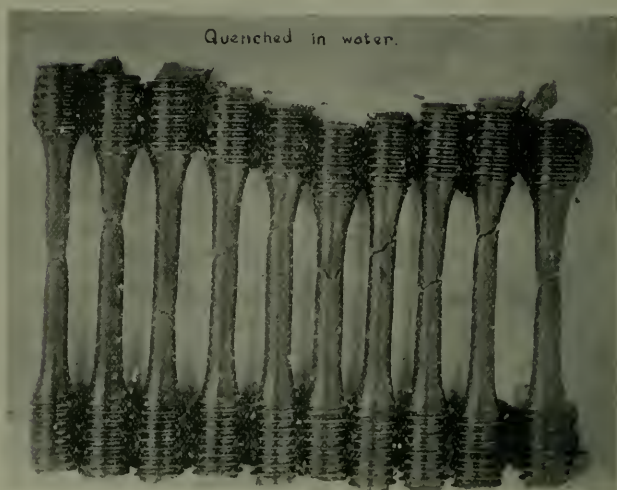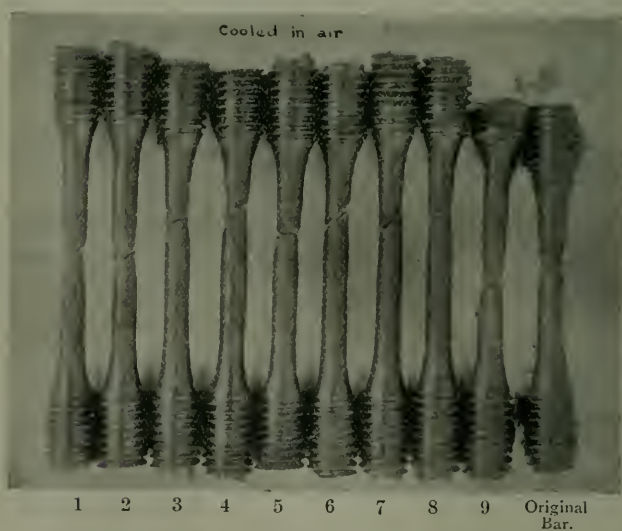
1   2   3   4   5   6   7   8   9   Original
                                                    Bar.
FIG. 2.

Broken Test-pieces of the 20 Bars used in the Experiments.

raise the tenacity and to reduce the elongation and contraction of area at the point of fracture.

On comparing the results obtained on the two bars of No. 1, heated to just above the critical point, it will be noticed that there is practically no difference in the tensile strength, the tenacity of the quenched bar being only 0·45 tons greater, the elongation 5 per cent. less, and the reduction of area at the point of fracture is 0·6 per cent. more than the respective results obtained on testing the air-cooled material.

The mechanical properties of the highly heated, air-cooled bars are surprisingly good, and not what was expected.

The best results, so far as ductility is concerned, are those obtained in the case of the bar heated for three months at 430° C. The lowest tenacity is found in the bar heated to 720° C., while that heated to 773° C. has the lowest ductility. The most astonishing results, however, are those produced on heating to 860° C., which show only 1·1 ton less tenacity and 2 per cent. less elongation than the bars heated to 475° C.

Generally speaking, the ductility of the air-cooled bars decreases with rise of temperature until 773° C. is reached, and then increases with higher heating—a remark which is equally applicable to the bars quenched in water, for the elongation decreases from 45 per cent. in the bar heated and quenched from 475° C. to 10 per cent. in that heated and quenched from 773° C., and rises with higher heating to 30 per cent. in the bars heated to and quenched at 860° C.

In the quenched bars, however, the tenacities compared with the duplicate air-cooled bars are, with the exception of No. 6, greater, as is shown in the table hereunder:—

				Difference of Tenacity between the Quenched and Air-cooled Respective Bars.	
				Plus. Tons.	Minus. Tons.
Bars heated to 475° C.	.	.	.	0·45	...
,, 565° C.	.	.	.	0·80	...
,, 675° C.	.	.	.	0·80	...
,, 720° C.	.	.	.	2·92	...
,, 749° C.	.	.	.	2·35	...
,, 773° C.	.	.	.	...	1·74
,, 812° C.	.	.	.	4·03	...
,, 833° C.	.	.	.	3·73	...
,, 860° C.	.	.	.	2·80	...
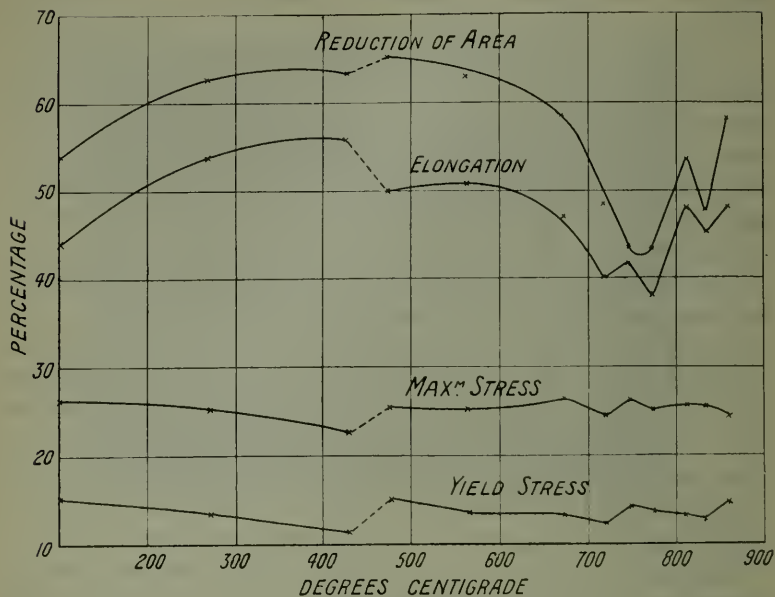
DIAGRAM A.—Results of Mechanical Testing.
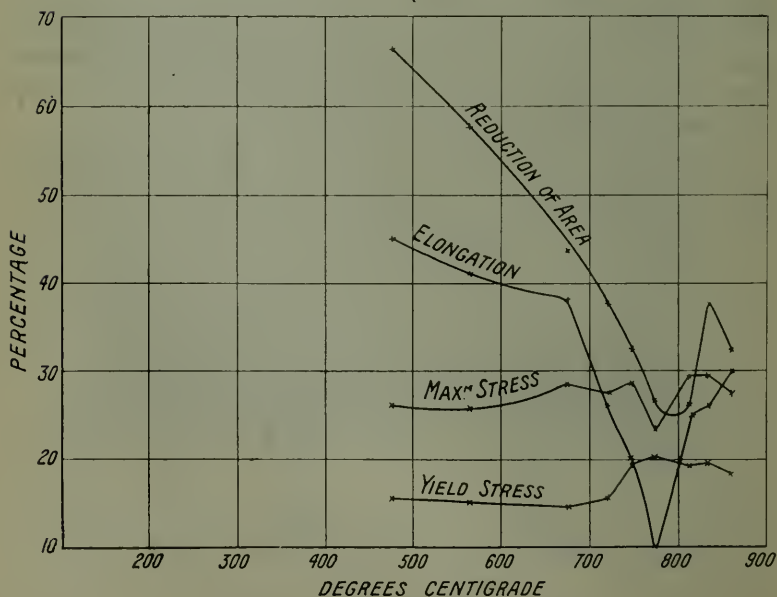
DIAGRAM B.—Results of Mechanical Testing.

It is obvious from these results that in the neighbourhood of 773° C. there is a critical or weak point for this particular brass.   Some authorities maintain that 750° to 780° C. is a dangerous zone.   Brass heated in that zone has been described as " burnt "—a term, however, obviously inappropriate, for, on higher heating, the material again becomes ductile.

PART II.

MICROSTRUCTURE OF THE ALLOYS.

All the specimens referred to in Part I., after polishing, were etched with a dilute solution of ferric and hydric chloride. The β constituent was fully developed in about ten seconds. After etching, the surfaces were dried with a clean linen rag.

Speaking broadly, as the temperature rises above 470° C. the β constituent increases in accordance with the equilibrium diagram of Shepherd, and when the temperature of heating is a little above 773° or 812° C. the metal specimens consist wholly of the β constituent, which is retained as such—after quenching.

" A " *Alloy.*—In the brass designated " A " the β constituent gradually diminishes during heating to about 430° C. until most of it disappears, and it seems to be probable that if the heating had been prolonged for six months instead of for three, all the β constituent would have been absorbed, or, in other words, the alloy would have become entirely α.   The result apparently indicates that the curve b2–b3 in Shepherd's diagram should turn to the right after passing about 500° C. instead of being vertical.

The gradually diminishing size of the β segregations does not suggest that the β constituent changes to the γ and α constituents, but that the change is similar to what occurred on reheating to 500° C. one of the specimens that had been heated and quenched from 700° C. or above, for by such treatment the β constituent gradually diminishes, and the α constituent increases.

Careful microscopic examination of the β constituent in

I

the long-heated alloy failed to detect any clear evidence of segregated γ, and one is therefore tentatively inclined to hold the view that the β constituent which disappeared simply dissolved in the α, increasing its total mass and producing the α with a less amount of copper than 62 per cent.

"B" *Alloy*, heated for 984 hours at 270° C. (Photo No. 4a, Plate II.).

The structure of this alloy is but slightly different. Some of the α particles appear in globular form embedded in the β constituent, which were not present in the original alloy. The mechanical properties are but slightly different from those of the original annealed bar.

Nos. 1 *and* 2 *Bars*, heated respectively to 475° and 565° C. (Photos Nos. 5a and b, 6a and b, Plate III.).

Here the structure is that of particles of the β constituent embedded in α, and generally separated from each other. The α is in greater mass, and the amount of β is about the same in both the quenched and air-cooled material. These facts explain why there is little difference in the physical properties of the quenched and air-cooled bars, the quenched bars having a greater tenacity of 0·45 and 0·8 ton respectively than the duplicate bars cooled in air.

Nos. 3, 4, 5, *and* 6 *Bars*, heated respectively to 675° C., 720° C., 749° C., and 773° C. (Photos Nos. 7a and b, 8a and b, 9a and b, 10a and b, Plates IV. and V.).

The proportion of β in the quenched bars increases with the temperature of heating, which accounts for the increased tenacity of the quenched bars, because β is the harder constituent. The elongation decreases considerably, with the appearance of strips of α connecting the larger grains of the same substance. The envelopes of α in No. 6 account for the great weakness. The photograph No. 17 shows that on bending this alloy it is the α which first gives way.

Nos. 7, 8, *and* 9 *Bars*, heated respectively to 812° C., 833° C., and 860° C. (Photos Nos. 11a and b, 12a and b, 13a and b, Plates V. and VI.).

Heated at temperatures sufficiently high to produce homogeneous β constituent, free from any α, these alloys after quenching in water are, as one would expect, of higher

tenacity than those heated to, and quenched at, lower temperatures.

No. 8 alloy quenched from 833° C. has a greatly increased tenacity and ductility as compared with No. 6 alloy. The tenacity has risen 6 tons, the elongation 16 per cent., and the contraction of area 11 per cent.

No. 9 alloy, when removed from the furnace, showed signs of incipient melting.

The microstructure of the air-cooled alloys resemble each other, and are all of the banded type, consisting of strips of α separated by β. The same type of structure can be traced in the quenched specimens when highly magnified, as is shown in Photo No. 14, Plate VI., which somewhat resembles the martensite structure of highly heated and quenched low-carbon steels. It is possible that had the pieces of metal been smaller and the quenching more sudden, the β constituent would have been more homogeneous, for, in our opinion, the structure shown in Photo No. 14 is caused by incipient separation of the α constituent, due to insufficient rapidity of cooling. The structure is analogous to that of steels containing 0·20 per cent. carbon quenched in water from 1000° C., in which the triangular markings, in lighter shade, represent the incipient separation of ferrite, or free iron, from the martensite.

When a bar of brass containing about 60 per cent. copper is heated to 860° C. at one end, and to about 500° C. at the other, and is then cooled in the air or quenched in water, all the structures illustrated in Photos Nos. 5 to 12, Plates III., IV., and V., are obtained in one piece. When a bar is heated and cooled alternately for 30 or 40 times in the range of temperature between 600° C. and 700° C., and is cooled slowly after each heating, the independent particles of α constituent increase to a great size, and suggest by their shape a tendency to form idiomorphic crystals. One is not prepared to give a definite reason for this; it is probably due to the very slow cooling after each heating.

Before the larger bars were heated for mechanical testing, small pieces were heated to approximately the same temperatures, and it is remarkable how close the corresponding structures really were. It may be concluded, therefore, that having

the structure of 60/40 brass, the temperature of annealing between 500° C. and 860° C. may be judged approximately.

The whole of the illustrations in this paper, excepting those of Part III., were obtained by slightly etching the metals so as to show only the α and β constituents. On stronger etching the orientation of the β constituent can be developed. In the specimens heated to above 500° C. and under 812° C., the β constituent develops into larger crystals, which are readily detected by the reflections from the etched surfaces when the specimens are rotated and illuminated by rays of incident light. The α particles appear as islands in the β crystals, but the orientation of the α has not been determined.

In a bar heated and cooled many times gradationally, the β crystals extended continuously side by side in long parallel columns for a distance of nearly three inches, within the temperature range of 550° C. and 800° C. The crystalline orientation was heterogeneous in the parts of the metal heated above 800° C. and below 550° C. Heating at about 812° C. does not appear to lead to the growth of such large crystals as are formed below 800° C. They do, however, steadily increase in size as the temperature is raised above 800° C. On straining the crystals of β of No. 6, quenched alloy, slip bands appeared, as shown in Photo No. 15, Plate VI.

The Property of Brass in Resisting Oxidation on Heating in Air.

Incidentally during this research it was found that on heating yellow brass in air, even for 48 hours, the loss by scaling and oxidation was remarkably low. The bars used for mechanical testing were weighed and measured before and after heating, and the losses in weight were determined, with the following results :—

> Nos. 1, 2, 3, and 4 lost less than 0·2 per cent.
> Nos. 5 and 6 lost about 0·3 per cent.
> Nos. 7, 8, and 9 lost about 0·8 per cent.

Bars of cupro-nickel heated at 860° C. for 48 hours lost nearly 12·5 per cent. by scaling, or about 18 times more

than the yellow brass that had been heated under the same conditions. The scale from the yellow brass consisted entirely of zinc oxide free from even a trace of copper.

The analyses of the bars before and after heating were as follows :—

	Hard-drawn Original Bar, Series 1–9.	After heating to 860° C. for 48 hours.	Bars used for Series A and B.
	Per Cent.	Per Cent.	Per Cent.
Copper	60·40	60·89	61·04
Zinc	39·43	38·93	38·72
Lead	0·09	0·09	0·09
Arsenic	0·01	0·01	0·01
Iron	0·05	0·05	0·05
Total	99·98	99·97	99·91

The increase of copper shown in the second column corresponds most closely with the analyses calculated on the basis of the loss of 0·8 per cent. zinc. The outer layer of the alloy, Nos. 3 to 12, consisted of a only (Photo No. 16, Plate VI.).

As the bars were placed close together during heating, and free circulation of air was restricted by the plugs of asbestos at each end of the heated furnace tube, other trials were made in which pieces of brass and copper, of the same shape and dimensions, were heated side by side for several hours, at about 850° C. in a large gas-heated muffle furnace. The muffle was not closed in front, and air freely circulated round the metals. The weight of each metal was about 50 grammes. After removing them from the muffle, the scale was carefully detached from each bar. The scale from the Muntz metal weighed 0·49 gramme, and consisted entirely of zinc oxide free from the slightest trace of copper.

The scale from the copper weighed 2·88 grammes.

The bars lost in weight :—

	Per Cent.
Copper	4·60
Brass	0·80

Ratio of loss, copper to brass, 5·7 to 1.

After the trials of Professor Turner, in which he heated brass in vacuum and obtained a much greater removal of zinc

than is here shown, it must be concluded that pressure plays an important part in preventing the escape of zinc from such material. The remarkable feature here proved is that the presence of zinc completely prevents the oxidation of copper.

Summary of Results.

It is sufficient to state that under the conditions named—

1. Cold-drawn Muntz metal is obtained in the most ductile condition by annealing at 430° C. for 3 months.
2. It is dangerous to anneal between 750° C. and 800° C., because the β crystals are liable to become enveloped with α—a structural arrangement conducive to weakness in both chilled and air-cooled material.
3. Heating to between 800° C. and 830° C., followed by quenching, leaves the metal as homogeneous β constituent, which has a tenacity of about 29 tons per square inch, as compared with 26 tons per square inch in the metal annealed at 500° C., with an elongation of 25 per cent. in 2 inches.
4. Heating to between 800° C. and 833° C. and cooling in air leaves the metal almost as good as it was after annealing at 500° C., and heating the metal at just above 800° C. causes it to re-crystallize into finer grains than are formed at between 500° C. and 800° C.
5. Brass is remarkably immune from oxidation during heating, and only 0·8 per cent. was oxidized on heating for 48 hours at about 860° C. compared with 4 per cent. for copper, heated under similar conditions.
6. It is only the zinc which is oxidized on heating Muntz metal, and the scale detached from heated bars consists entirely of pure zinc oxide.

What still requires investigation is :—

1. The minimum percentage of zinc, when alloyed with copper, which will prevent the oxidation of the latter during heating.

2. Whether very prolonged heating of 60/40 brass at temperatures below 470° C. will cause it to become pure *a* constituent, free from *β*, to check previous work.

In conclusion, we must express regret that we have left so much work still to do, and therefore request that this short communication be regarded as an introduction to more exhaustive trials.

We thank Mr. F. Tomlinson of Messrs. The Broughton Copper Company, Limited, Manchester, for having supplied the necessary material on which to work; Mr. D. Terrace and his assistant, Mr. Blincoe, for making special arrangements for facilitating the heating of some of the bars at the Middlesbrough Gasworks, and Messrs. The Sheffield Testing Works, Limited, for so carefully testing the experimental bars, and the Cleveland and Durham Electric Power Company for supplying the necessary current used in the annealing tests.

PART III.

A SIMPLE METHOD FOR DISTINGUISHING THE *a*, *β*, AND *γ*, WHEN ASSOCIATED IN BRASS.

By J. E. STEAD.

In 1900 I suggested that certain polished alloys could not only have their structure developed by "heat-tinting," or heating in air until they assumed tints of various colours, but that by heating in gases other than air the structures might be equally well developed.

The *a* and *β* constituents, when associated in relatively large masses, are readily identified by etching with acidulated ferric chloride, the *β* constituent being acted upon to a greater extent than the *a*, and remains in slight depression.

There can, however, be little doubt that it is better to have perfectly flat surfaces for microscopic examination. All etching reagents make the surfaces more or less uneven. Tinting

by oxidation or by any other means is not open to that objection, the surfaces remaining perfectly flat. The aim of metallographers should therefore be to develop the tinting methods wherever possible.

The useful brasses and those containing small portions of the γ constituent can be very rapidly tinted by blowing air containing traces of ammonium sulphide, chlorine, bromine, &c., upon the specimens when in a heated condition. Even in the cold state the α constituent is tarnished by that means, and the more rapidly, the higher the content of copper. Tinting in the cold, however, is open to the objection that minute specks of moisture are liable to condense on the polished surface and produce a spotted and false colouring.

The simple method I have now adopted consists in finishing the polishing on a very wet block, drying the surface of the specimen with a clean linen rag before the water has evaporated from any part of the surface of the metal, heating to $80°$ C. or $100°$ C. and rubbing with a piece of soft chamois leather, floating the metal on molten tin or lead, and then directing upon the metal a gaseous mixture made by blowing air through a weak solution of ammonium sulphide placed in an ordinary wash-bottle with reversed tubes until the desired tints appear.

The α constituent passes through the range of colour dark yellow, brown, carmine, blue to slate grey. The γ constituent when associated with the α constituent remains unaltered, and appears white on a brown, red, or blue ground, according to the degree the fuming has been carried.

In order to demonstrate the value of this method a specimen of 70/30 brass was polished, and into its face was crushed particles of pure γ sprinkled on a hard steel plate. By that means some of the particles became embedded in the metal. After polishing, the γ constituent was seen to be of a dove colour on a yellow ground.

Photo No. 17a, Plate VII., represents one of the areas containing γ surrounded by α as seen on the polished alloy. The metal was then heated by floating it on melted tin, and a stream of air carrying ammonium sulphide was blown upon its surface. In two seconds the surface changed to a red

PLATE II

No. 3.
Disintegrating Rod of Muntz Metal, overstrained by cold-drawing.

With the exception of Nos. 14 and 15, the whole of the following photographs represent magnifications of 50 diameters.
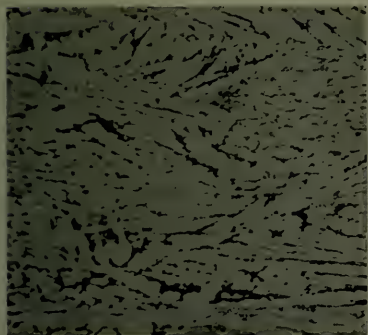
No. 4.—Alloy A.
Normal.
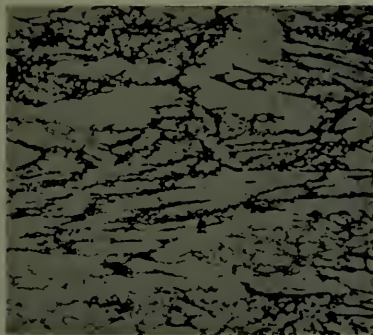
No. 4a.—Alloy B.
Alloy A after heating for 984 hours
at 270° C.

PLATE III
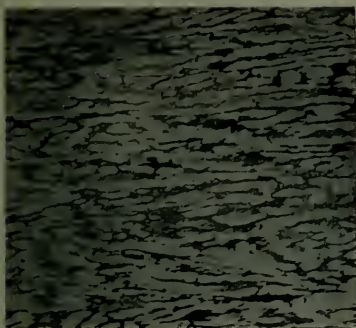
Original Hard-drawn Bar.
Series 1-9.
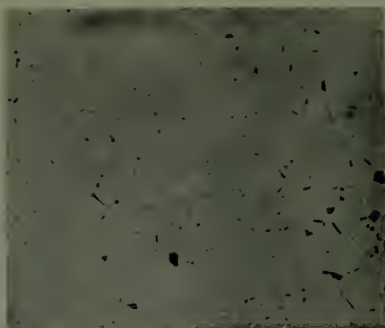
Alloy A. Heated for 3 Months at 430° C.
Series A and B.
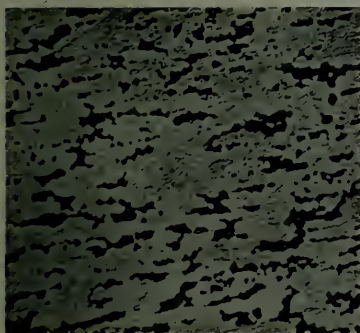
No. 5a.
Quenched.
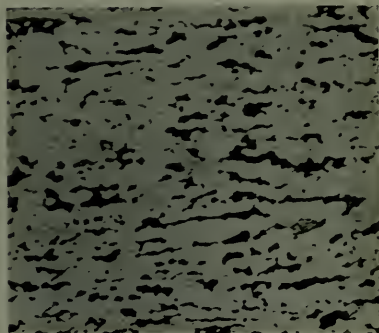
No. 5b.
Cooled in Air.

Bar No. 1.—Heated to 475° C.
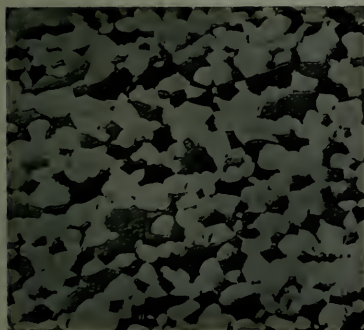
No. 6a.
Quenched.
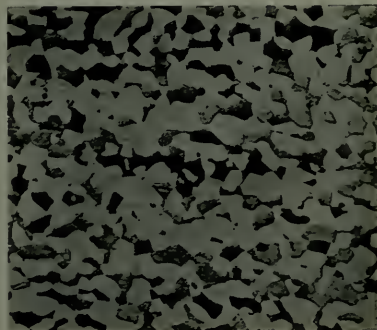
No. 6b.
Cooled in Air.

Bar No. 2.—Heated to 565° C.

PLATE IV
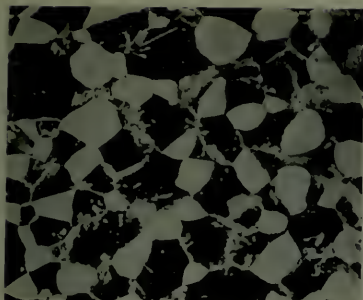
No. 7a.
Quenched.
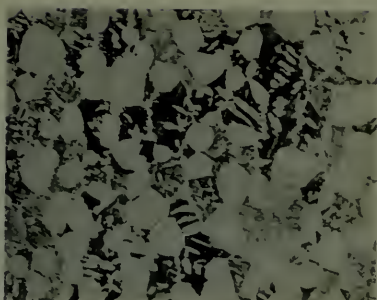
No. 7b.
Cooled in Air.

Bar No. 3.—Heated to 675° C.
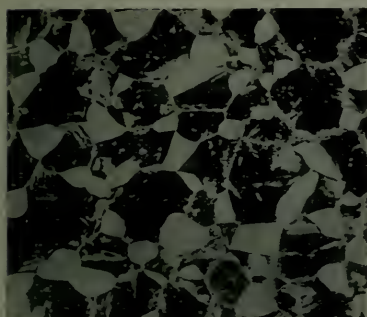
No. 8a.
Quenched.
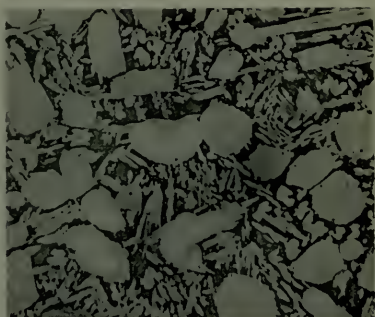
No. 8b.
Cooled in Air.

Bar No. 4.—Heated to 720° C.

No. 9a.
Quenched.
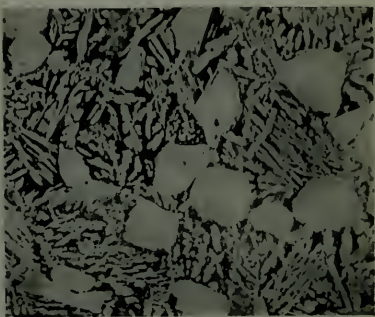
No. 9b.
Cooled in Air.

Bar No. 5.—Heated to 749° C.

PLATE V

No. 10a.
Quenched.
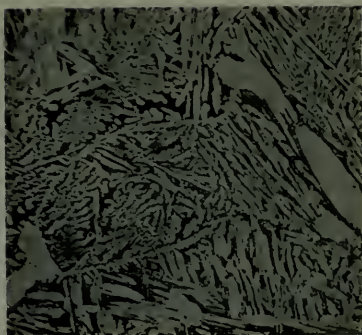
No. 10b.
Cooled in Air.

Bar No. 6.—Heated to 773° C.

No. 11a.
Quenched.
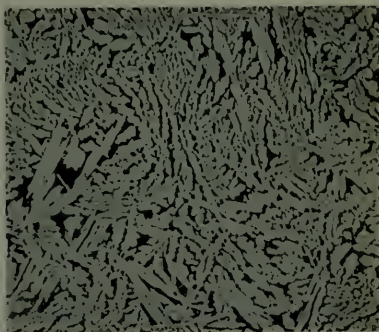
No. 11b.
Cooled in Air.

Bar No. 7.—Heated to 812° C.

No. 12a.
Quenched.
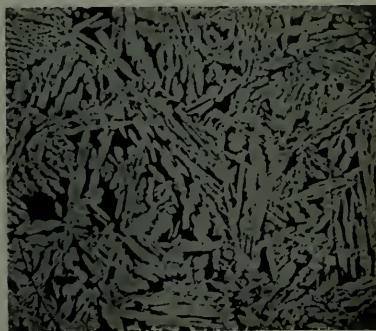
No. 12b.
Cooled in Air.

Bar No. 8.—Heated to 833° C.

PLATE VI
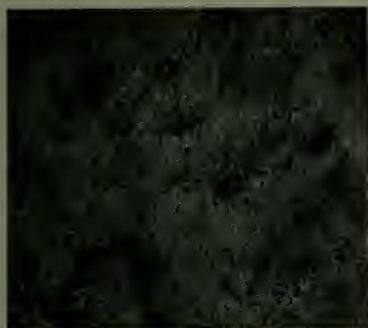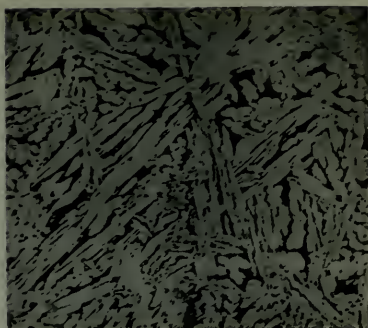
No. 13a.
Quenched.

No. 13b.
Cooled in Air.

Bar No. 9.—Heated to 860° C.

No. 14.
Same as No. 13a.
Magnified 330 diameters.
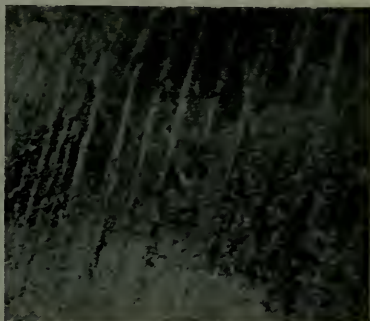
No. 15.
No. 6 Bar after Straining, showing Slip
Bands in β.
Magnified 330 diameters.
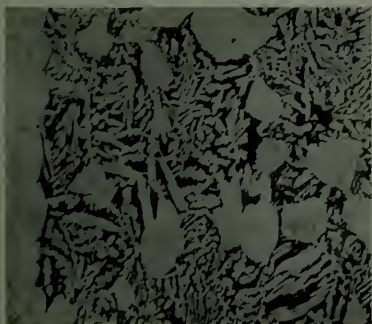
No. 16.
No. 5 Bar, showing External
Layer of α.
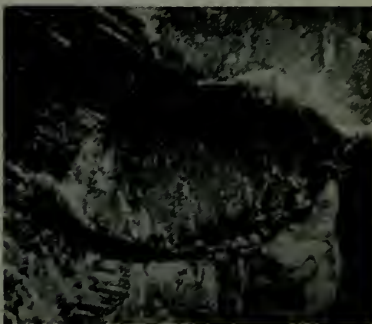
No. 17.
No. 6 Bar, Quenched, Strained, showing
weakness of α Envelope.

PLATE VII

No. 17a.
Polished only.

No. 17b.

Fumed with
Ammonium
Sulphide.
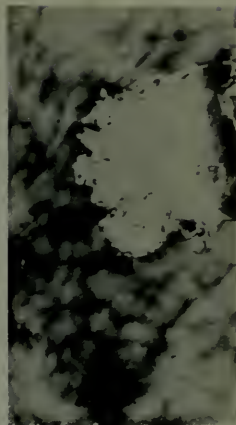
No. 17c.

No. 17.—γ in α (White in Dark).

No. 18a.
Polished only.
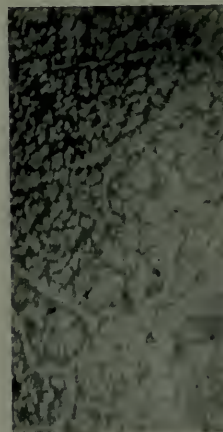
No. 18b.
Fumed by New Method
Ammonium Sulphide.

No. 18c.
Fumed by New Method
Bromine.
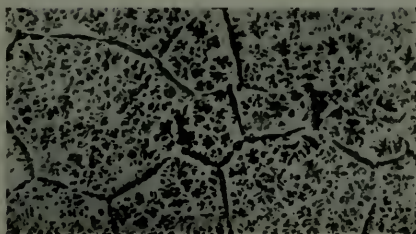
No. 18d.—Etched with Ferric Chloride, γ Black.

No. 18.—γ in β.

colour. It was cooled, examined, and photographed with the result shown in Photo No. 17*b*, Plate VII. The specimen was thereupon floated on liquid lead and sulphurized a second time, until the α constituent appeared nearly white but variable in colour. The γ constituent still appeared much the lighter, as shown in Photo No. 17*c*, Plate VII., but in addition to γ there appeared primary dendrites in nebulous form. Photos No. 18*a* and 18*b*, Plate VII., illustrate the γ and β constituents in juxtaposition before and after sulphurizing. The contrasts are slight in the polished, and clear in the fumed, specimen.

In developing the structure of β in the presence of γ it is preferable to use air containing traces of bromine instead of ammonium sulphide, as it is more rapid in its action.

The evidence is conclusive that by this simple method—

1. The slightest variations in the distribution of copper in brasses containing between 90 and 64 per cent. can be detected by fuming the heated polished surfaces for a few seconds with air impregnated with ammonium sulphide, bromine, &c.

2. Even in worked and long annealed commercial brasses traces of the dendritic primary crystallites can be detected.

3. The γ constituent can be detected when associated with the α constituent.

4. It is applicable to the development of the structure of bronzes and other alloys rich in copper.

PART IV.

THE DEVELOPMENT OF BRITTLENESS IN HARD-DRAWN BRASS.

Occasionally brittleness in old brass wires has, in our experience, been noticed, and we have never been able to account for it.

Mr. F. Johnson, when discussing the paper on " A New Critical Point in Copper-Zinc Alloys," by Professor H. C. H.

Carpenter and Mr. C. A. Edwards,[*] remarked that it was well
known that brass which has been finished hard (that is to
say, hardened by mechanical treatment) was susceptible to
" age cracking " or " secular brittleness." A remarkable ex-
ample of this was afforded in a specimen of hard-drawn brass
rod, which had been used as a conductor for high-tension
electric current through the concrete floor of one of the
Cleveland and Durham Power Company's sub-stations. After
long use—about three years—these rods began to crack. A
number of them were removed and a careful examination
made. In Photograph No. 3 (Plate II.), full size, there is re-
produced a longitudinal section of a piece broken from one
of these rods, which was originally 23 inches by $\frac{5}{8}$ inch in
diameter. When removed, the cracks were found to be
filled with a bluish-white powder, consisting of nitrates of
copper and zinc, which had been produced by the effect of
electrical discharge across the air space between the charged
rods and the surrounding insulator, which in passing through
the air produced the higher oxides of nitrogen, which then
attacked the brass. This powder had accumulated in the
cracks and had evidently exerted pressure, which would, of
course, tend to extend the fractures. The portions of the
brass enclosed by the threaded nuts on each end of the bar
were perfectly sound and free from incipient cracks—an in-
dication that the bar itself when put to use must have been
of the same character. The direction taken by the cracks
clearly indicates that it was along the planes of weakness
produced by cold drawing, for, as will be seen in the photo-
graph, they travelled in such a way as to produce the well-
known cup and cone fracture, often seen in so-called " cuppy
steel wire"—sometimes the result of overdrawing. Over-
drawing leaves the metal weak along conic surfaces, and when
the reduction of area is too great, fractures of the cup and
cone type occur when passing through the draw plate. If the
reduction of area is just insufficient to cause rupture, the
internal stresses must be excessive.

The conductor rods when in use were in a constant state
of tremor, and there can be no doubt that where they were

not securely held at the ends by the screwed nuts, this tremor gave impetus to internal rupturing, and eventually caused the rod to break into pieces.

The analysis of the brass rod was as follows :—

								Per Cent.
Copper	.	.	.	.	.	.	.	58·61
Zinc .	.	.	.	.	.	.	.	38·61
Lead	.	.	.	.	.	.	.	2·40
Tin .	.	.	.	.	.	.	.	0·25
Iron .	.	.	.	.	.	.	.	0·08
								99·95

The presence of lead is conducive to weakness, and it is possible that had lead been absent failure would not have occurred.

The hardness by Brinell's machine was 119, and on heating to 440° C. for one hour it fell to 109; but after heating to 700° C. for one minute and cooling, this fell to 77, or a drop of 42 hardness degrees, showing that all the hardness produced by cold working was removed by this simple treatment, and we have no doubt that had the rods been so heated before being put into use the internal stresses would have been destroyed, and in spite of the lead present the bars would not have broken down.

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Carpenter, "The Structural Resolution of the Pure Copper-Zinc β Constituent into a and γ." *Journal of the Institute of Metals*, No. 2, 1912, vol. viii. p. 51.

Carpenter, "The Effect of other Metals on the Structure of the β Constituent in Copper-Zinc Alloys." *Journal of the Institute of Metals*, No. 2, 1912, vol. viii. p. 59.

DISCUSSION.

Dr. J. E. STEAD, D.Sc., D.Met., F.R.S., on introducing the paper, stated that in a recent issue of a technical journal * there was an abstract from *Materialienkunde* giving an account of a research by Professors Martens and Heyn on the properties of hard-drawn Muntz metal rods.

These gentlemen had found that such material when placed in a solution of mercurous nitrate cracked with a loud noise in a longitudinal direction. The cracks opened out at the surface, showing that the outer layer was in great tension. After drilling down the centre of another rod of the same material, so as to remove the metal which the outer layer compressed, the envelope contracted and the tensional stresses were removed. That was proved by the cylinder no longer breaking up on placing in mercurous nitrate.

Dr. Stead demonstrated the value of the mercurous method of treatment for showing the presence of internal stresses in a hard-drawn Muntz metal rod, by placing it in the reagent, when in a short time surface cracks developed.

Sir HENRY J. ORAM, K.C.B., F.R.S. (President), said that it was quite obvious that a very large amount of work still remained to be done with regard to the influence of heat and also of heat treatment on metals. He wished to say how sorry the Institute was that Sir Gerard Muntz was not present to take part in the discussion of the paper. As the members knew, Sir Gerard had been very seriously ill, but the latest reports were that he was going on very satisfactorily, and the members hoped to see him very soon again amongst them.

Professor T. TURNER, M.Sc. (Vice-President and Honorary Treasurer), said that there were possibly other members present who had had more experience of Muntz metal than he himself had. A number of experiments in connection with the metal had been conducted in the University at Birmingham, and he hoped Mr. Hudson and Dr. Bengough would be able to say something on the matter at a later stage.

Dr. Stead had given to the members, as he always did when he read a paper, a very interesting communication indeed. Dr. Stead's papers somewhat reminded him of a lady's letter, in which the postcript was usually the most interesting part. In the same way Dr. Stead's further explanation that day was almost as, if not more, interesting than the paper itself.

With reference to the ageing of Muntz metal and the cracks which formed in it, especially when it had been overworked, those were matters of common knowledge to all who were connected with the trade, but to have them brought before the Institute in so very definite a manner was very striking, and Dr. Stead would be placing the Institute under an

* *The Metal Industry*, vol. vi., No. 3, p. 108.

obligation if he left the specimen which he had exhibited that day to the Museum of the Institute as an example of a " diseased metal."

When the figures which Dr. Stead had given of the tensile strength, and of the elongation of the alloys as heated and quenched at different temperatures, were read, it would be found that they were in general accordance with what might be anticipated from the known properties of the a and β alloys, and from the equilibrium diagram of Shepherd, which had now been fairly well confirmed in most of its points.

He did not propose to go into further details, but he should like to express to Dr. Stead his personal pleasure in listening to the paper and his interest in the important results which had been brought forward.

Professor A. K. HUNTINGTON, Assoc.R.S.M. (Past-President), ex- pressed the appreciation which the members felt at seeing Dr. Stead present. They had always looked upon him as a man, he would not say of "blood and iron," but a man of brains and iron, without a bit of brass about him, unless it be in the lining of his pockets ! The members very much appreciated having Dr. Stead amongst them and contributing a paper.

Dr. Stead, on page 134, expressed himself somewhat surprised that the zinc was so powerful in preventing oxidation of the copper. He (the speaker) thought that all those who came into daily contact with brass realized that the zinc prevented oxidation of the copper by volatilizing, and thus forming a very thin atmosphere over the alloy, so that the copper did not come into contact with the air. The oxide which was formed also helped in that direction.

On page 134 Dr. Stead referred to "a structural arrangement con- ducive to brittleness." * He (the speaker) would like to see the term " brittleness " modified, because he did not think an envelope of a round β caused brittleness. It caused weakness in a sense, because the a was very much weaker than the β, and naturally the break occurred round the envelope eventually. Dr. Stead said that when a certain point in the heating was reached, very considerable weakness developed. He (the speaker) thought he might perhaps throw some light on that, because he had made a very great many experiments extending over several years. They had been, in fact, published in connection with a patent, and curves were given.

As the β point was approached from the all-a limit the elongation gradually went down. Then something happened which he certainly did not know before and certainly did not suspect, namely, the elonga- tion in the β range rapidly increased up to the γ point and then it came down suddenly. The very opposite occurred with the yield point. The surprising thing was that up to the present time the β range had been considered as a range where there was increasing reduction in the elongation, but nothing of the sort occurred. The alloys were copper and zinc with aluminium and manganese varying up to 2 per cent. each

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* [In the finally revised paper Dr. Stead altered the word brittleness to weakness, as explained by Dr. Stead in his reply on p. 147.—ED.]

and say 1 per cent. of iron.   Dr. Stead, on page 127, says, " The elongation decreases from 45 per cent. in the bar heated and quenched from 475° C. to 10 per cent. in that heated and quenched from 773° C. and rises with higher heating to 30 per cent. in the bars heated to and quenched at 860° C."   And on page 129 he says, " When the temperature of heating is a little above 773° or 812° C. (*sic*) the metal specimens consist wholly of the β constituent, which is retained as such after quenching."

There was one question he would like to ask Dr. Stead, namely, whether the rod he had exhibited to the members that morning had been heated up at all.

Dr. STEAD replied in the negative.   The rod had never been hot, although the house was rather warm.   The actual rod itself had not become at all heated.

Professor HUNTINGTON, continuing, said the point he had in mind was, Did heating electrically have any effect?   Electric heating had quite a different way of heating to ordinary heating, because the heat was at first greatest at the centre of the bar, and it must put a very considerable strain on the outer portion.   The outer portion would be cooler and the centre hotter.   In the ordinary way of heating, at first the outside was hotter and the centre cooler.   He was only wondering whether the possible heating had anything to do with it.   Beyond that, it was well known that when a rod was subjected to cold working, one never obtained the work uniformly right through to the middle, and that the outside was very much more worked than the inner portion, which accounted for a good deal.

Mr. G. A. BOEDDICKER (Vice-President), said that when he saw the rod which Dr. Stead had exhibited, it seemed to him very familiar and very much like an old friend.   He would have no difficulty in producing one like it at any time from the metals with which he dealt, especially high-class German silvers.   When a bar of German silver was drawn down cold and put into an annealing furnace it broke exactly like the specimen shown.   This could be prevented by a process known among the workmen as "springing."   What effect that had he had no idea, but undoubtedly there was a great deal of internal tension in a rod like the one exhibited, and this tension could be removed by hammering, bending, or undulating the rod, which could then be annealed without any fear of fire cracks.   Again, if it was drawn on a block "springing" was generally unnecessary.   He thought brass sometimes acted in the same way, and that the rod shown, which was hard drawn and not "sprung," got heated or warmed through the electricity passing through, thus causing it to crack.   He was afraid that it would be almost impossible to show the effect of springing under the microscope, as the operation of polishing itself would be probably sufficient to remove any internal tension.

Mr. O. F. HUDSON, M.Sc. (Birmingham), said that he desired first of all to join in welcoming Dr. Stead at the meetings of the Institute, and he thought the Institute was to be congratulated on having a paper from him.

He was glad to find that Dr. Bengough's and his own results showed in a general way such good agreement with those of the authors. There was one point on which there seemed to be an important difference, and that was the marked recovery of ductility found by the authors after annealing for forty-eight hours at temperatures above about 775° C. Possibly this could be accounted for by the long annealing time (forty-eight hours), or by some difference in the rate of cooling as compared with the annealing conditions of Dr. Bengough and himself. It would be of interest to have some further experiments on this point.

He was in entire agreement with the authors in regard to the weakness of the α envelope which was found surrounding the β under certain conditions of heat treatment. Dr. Bengough and himself, in their study of the course of the fracture in Muntz metal, were able to show that not only in this case, but also generally, the fracture had a tendency to pass through the α, the more ductile constituent, rather than the β.

Under the third heading of their Summary of Results the authors refer to the properties of homogeneous β. The photographs given, however, seem to show that really they were not dealing with pure β, but with an intimate mixture of α and β. Then, again, he might point out that the recrystallization, referred to under the fourth heading, was generally known, but he was not quite sure that one could call it a structure of a finer grain. The separate crystals of α and β themselves were rather small, but it was usually noticed that these were more or less distinctly arranged in groups or grains of a comparatively large size.

With regard to the zinc-oxide scale, he had been under the impression that that scale was mainly zinc oxide, but he was rather surprised to hear that it was pure zinc oxide without a trace of copper. He had examined scale from Muntz metal qualitatively, and had found it contained a small percentage, but still an appreciable amount, of copper. In Dr. Bengough's and his own paper on the 70 : 30 brass they made some experiments on the extent of the loss of zinc during the annealing of that alloy, and discovered that the loss of zinc was not very great even at high temperatures, and extended only a short way below the surface. On looking through their notes on the subject he had found that in one case they had analyzed the scale from 70 : 30 brass, and had found in that 10·2 per cent. of copper—a fact which in the present connection might be of interest to Dr. Stead.

Finally there was the question of the method of developing structures which Dr. Stead described. He was very glad to have the details of Dr. Stead's fuming method, which would doubtless be of great value in certain cases. He (the speaker) thought, however, that if Dr. Stead's photographs were examined, in the case of β and γ, it would be found that the structure developed by ordinary etching was rather clearer and better than that developed by the fuming method ; and his own experience, extending over a number of years, was that the best method of

developing the structure of zinc-copper alloys was a gentle polish attack, ammonia being used. He had found that method not difficult or tedious, and he thought that generally it gave a decidedly more reliable result than any staining or tinting method.

As to the possibility of distinguishing γ and α when together, he had to confess that so far he had never been able to get a zinc-copper alloy in which those two occurred side by side, and he rather gathered in reading the paper that Dr. Stead had not been able to decompose the β. He would like to ask Dr. Stead whether he had any definite opinion on that point.

Dr. WALTER ROSENHAIN, F.R.S. (Member of Council), said that he also desired to associate himself with the expressions of welcome to Dr. Stead, and he hoped that Dr. Stead would bring the skill which he had so largely devoted to the study of iron and steel to bear on non-ferrous alloys to an increasing extent in the future.

With regard to the brass rod which Dr. Stead had exhibited, the speaker had examined a sample in his own laboratory some years ago which had come from an electric power station, and which was very similar to the one shown that day. The analysis of the metal was very much the same, and it was also hard drawn, but he had been able to find incipient drawing cracks even in the screwed ends. He took the trouble to have the actual current passed through the bar and the temperatures measured, and there was no perceptible heating at all, so that Mr. Boeddicker's theory was put quite out of court. It was entirely a question of the silent discharge. There was a very high voltage and a silent discharge between the rods and the insulator tube outside. This led to the formation of oxides of nitrogen, which entered the cracks and formed oxides and basic nitrates of zinc and copper, which disrupted the whole bar by their expansion.

Referring to the paper itself, there were two points of wider importance on which he desired to touch. First, with regard to the alloy (a) in which the β phase disappeared on prolonged heating. There were two possible explanations, which perhaps had been considered by the authors, but on which he would like a little information. In the first place, was Dr. Stead quite sure that it was not a question of the decomposition of the β into $\alpha + \gamma$, and the coalescence of this secondary α with the previously existing α, and that the residual γ had not been distinguished from β? If Professor Carpenter's views were correct on the matter, that is what ought to have happened. The other explanation was the possible removal of the zinc. It did not require the removal of much zinc to diminish the amount of β very considerably, and Dr. Stead had shown in his paper on page 133 that there was a distinct loss of zinc even after a few hours of annealing. He would like to know whether bar A had been analysed subsequently. If neither of those explanations held —and he rather imagined that they had been foreseen by the authors— then came the question of the correctness of the $\alpha/\alpha + \beta$ line in Shepherd's diagrams—in fact it raised the whole question of how far Shepherd's diagram really needed revision.

If Dr. Stead was right in suggesting that the $\alpha/\alpha + \beta$ line underwent a *sudden* swing to the right at some such point as P in the sketch, as shown by the dotted line PQ, then that would imply the existence of some such further line as OP dividing the α field.   In this connection it was interesting to remember that the α brasses, although very ductile when cold, were generally regarded as brittle when hot—although recently 70 : 30 brass had been rolled hot.   Still, a marked decrease of ductility at high temperatures was an abnormal feature in an alloy (shared only by a few other alloys), and required explanation by the constitutional diagram.   A line such as OP, indicating a transformation in the α phase, would afford such an explanation.

He next wished to refer to the method of " fuming " alloys.   It was
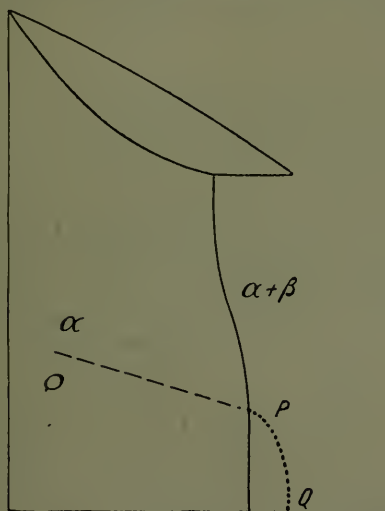
a very interesting and, no doubt, a useful method, and he had tried it successfully, but there were certain difficulties about it.   Even Dr. Stead's photographs showed that it was not easy to get a uniform stain, and the method had the disadvantage that it did not remove the altered surface layer produced by polishing.   He thought Dr. Stead and his colleague had perhaps claimed a little too much for the method, particularly in regard to the superiority of their method over etching, from the point of view of the flatness of the resulting specimen.   He had made a few measurements and calculations, which he would put before the meeting.   The actual thickness of the film removed when a piece of metal was etched in the ordinary way for microscopic examination might be fairly considerable, but what mattered was not the total thickness removed, but the difference of level produced between adjacent crystals.   In the case of his work on the transverse sections

of slip bands in 1906, he had occasion to examine transverse sections of a large number of etched specimens of iron and other metals, and he found that when they had slip bands on them it was perfectly easy to see on the sections little steps whose actual length was $\frac{1}{50000}$ of an inch. On the same sections the difference of level at the crystal boundaries in a lightly etched specimen were not resolvable, and from what was known of the resolving power of the microscope under the best conditions, that meant that those differences of level were of the order of $\frac{1}{200000}$ of an inch. That led one to ask the question, What was the thickness of the films of oxides and sulphides produced by fuming? They must be at least half a wave-length of light in thickness, otherwise they would be black, so that they would be probably twice as thick as the difference of level produced by a light etching, and the resulting surface was not flatter than that which was obtained by etching.

Mr. Arnold Philip, B.Sc., Assoc.R.S.M. (Member of Council), said that it was a well-known fact to all those who had to do with electric current, and to all electric engineers who were using regulating resistances, that regulating resistances on all carrying conductors of metal wire were liable to become brittle. It was not only characteristic of brass but also of German silver. In fact, of all metals of which he was aware, those best able to withstand this disintegrating action were nickel-iron alloys. He thought there must be a very large amount of information which the Institute did not possess, but of which electrical engineers were aware, and he would suggest to Dr. Stead that it might be of interest to make inquiries among the manufacturers of regulating resistances as to the difficulties they found from this action of electric current. This not only occurred in conductors which were kept warm by the current where the temperature rose and fell as the regulator was put in and out, but also in those cases in which the temperature was not very much altered and not very much above that of the atmosphere. The disintegration was much more marked in alloys containing zinc; in nickel, copper, and manganese alloys which contained no zinc, the trouble was much less.

With regard to the pure oxide layer on the external portion of the bar which Dr. Stead had noticed as being pure oxide, he (the speaker) suggested that the examples to which Dr. Hudson had referred, in which there was 10 or 12 per cent. of copper, referred to bars which had been heated externally. That was quite a different circumstance to that which occurred in those conductors in which Dr. Stead had noticed the pure zinc oxide layer.

Possibly the break-up of the faulty rods under the action of mercurous nitrate was brought about in the same way as the splitting up of alloys along the crystal faces by mercury, as described by Professor Huntington.

Dr. Stead, in replying to the discussion, stated that the object of their work was to obtain equilibrium at various temperatures by long heating

and to compare the structure and mechanical properties of metals after cooling in air and quenching.

The research was made, as previously stated, without knowledge of the work done by Messrs. Bengough and Hudson. There was some difference in the result, however; but in many respects the latter research agreed with the previous work. The difference in elongation of the bars heated to similar temperatures and slowly cooled might be accounted for by the difference in the time of heating and the size of the test-pieces. From a practical point of view the work of Messrs. Bengough and Hudson was the more valuable, for the reason that the duration of heating in their trials approximated more nearly to that of works practice.

Professor Huntington's suggestion (p. 141), that the term brittleness should be replaced by weakness was a good one, for as a matter of fact the specimens heated to and quenched from a temperature just below 800° C. were better described as weak than by the term brittle; he, Dr. Stead, had therefore changed the term in the revised paper.

He confirmed the finding of Messrs. Bengough and Hudson that 70 : 30 brass when heated was scaled with a substance that contained some copper; but he had always found a complete absence of copper in the scale that formed on Muntz metal—what was formed consisted of pure zinc oxide.

He had a considerable amount of interesting data about the physical properties of pure β, which he proposed at some future time to present to the Institute of Metals; but the research was not yet complete.

Mr. Boeddicker stated that by "springing" hard-drawn rods they became less liable to fracture. By "springing" he understood the jumping or bouncing of the coils after drawing.

Mr. BOEDDICKER said that was so, or it could be bent or twisted through a straightening machine. It was the custom of the trade.

Dr. STEAD, continuing, said that coils of hard steel wire rods sometimes broke up into pieces when they were placed in the pickling tanks containing acid, a result due no doubt to the added internal stresses induced by the entrance of hydrogen.

If, however, the coils were loosened and allowed to spring out to their more natural curvature, and the tension was removed in this way from their convex or outer circumference, they no longer broke in the tanks.

The slight difference produced by springing the coils on the floor and the removal of the stresses in the coiled wire were, he thought, analogous.

In answer to Dr. Rosenhain he, Dr. Stead, had not found any traces of γ in the specimen heated for three months at the melting-point of zinc. He had not found that any zinc had volatilized during this long heating, and no zinc oxide scale had formed on the surface. In his own experience he had found that the tinted specimens were better for photographing on account of being more perfect plane surfaces, and he attributed the imperfect photographs one so often met with in published researches to differences in level of the etched specimens.

The apparent dark γ areas shown in their Photo No. 18, although clearly marked as the result of etching with ferric chloride, were not γ but a decomposition product on the surface of the γ below. The γ was indicated better by etching, but the natural colour of that substance was better shown by the fuming method, and the surfaces left after fuming were certainly more even. They had given this method as one likely to be useful ; but his advice to all workers was, try all methods and use the one they find the best.

COMMUNICATIONS.

Mr. T. Vaughan Hughes, Assoc.R.S.M. (Birmingham), wrote that the scheme of the authors' research appeared to be open to some objection. At present forty-eight hours' annealing was not generally practised in brass works. It was true that charged " pots " were placed in a furnace towards the end of a day's work—a furnace working at 600° to 750° C.—the fires afterwards being banked and the charge left in until the following morning (sometimes, but rarely, during the week-end). Obviously a furnace thus charged with cold pots filled with brass strip or wire was reduced in temperature, and eventually attained a low red heat at which it remained for some indefinite period of time, as against the ordinary half to one and a half hour annealing at the daily working temperature. Brass thus annealed was considered by many manufacturers to be superior in physical qualities to that annealed by the slower process.

In former papers and discussions he (Mr. Hughes) had referred to the fact that hastened annealing was subversive to the attainment of the best mechanical properties of many non-ferrous alloys.

The cause was not far to seek. The heat treatment processes had been considered of less importance than mechanical treatment. Huge sums of money were cheerfully expended on mechanical contrivances in works, but the outlay on furnaces was always meanly discussed. Thanks to the work of one of the authors and others on the heat treatment of steel, the eyes of non-ferrous metal workers had been opened to the effect of heat treatment.

The writer held that the time-temperature aspect of heat treatment of the non-ferrous alloys must be drastically revised. Such papers as the authors' were very helpful, and would, it was to be hoped, enlighten non-ferrous metal manufacturers. The tendency in the immediate past had been to anneal in the shortest possible time without regard to the best physical results in the product.

Returning to the paper (p. 122), he (Mr. Hughes) wrote that he was glad that the authors had drawn attention to the considerable variation in temperature during a forty-eight hours' run in an electric - tube furnace. Unless lagged and screened very thoroughly, he considered them most unsatisfactory as exact heating appliances. Notwithstanding this, the conclusion of many researches were based on the results of

treating in such furnaces without reference to the erratic variations in their temperature. Personally, he thought that unless a continuously recording pyrometer was used in heat treatment researches the results lost much of their practical value.

Here he would like to inquire if the authors had a self-recording pyrometer in their three months' and 984 hours' experiments ?

He had been surprised to find how variable the temperature of works flues really were when checked continuously by thermal appliances.

With regard to the times of cooling described, it was to be regretted that the authors did not cause these to approximate more closely to those obtaining in works practice, because, after all, it was one's daily experience that was under review. Ordinary cooling of a furnace charge did not take place in ten minutes. Even the quenching experiments recorded were open to objection in the matter of drop of temperature between leaving the furnace and quenching. Could not these be re-peated by enclosing one test-piece in a non-conductor so as to cool in, say, half an hour at least to air temperature ?

The sudden quenching could easily be arranged so that little drop in temperature of the test-piece should take place before it came into con-tact with the quenching liquid.

From experiments carried out on a larger scale than those of the authors, he believed that they would obtain other results tending to con-firm the opinion that it was undesirable to quench the brasses at the proper annealing temperature before they have been allowed to drop through a certain range varying with the composition of the alloy. The results of the authors' experiments confirmed those of others, viz. that quenched 60/40 brass was harder than the air-cooled material.

Mr. Sydney W. Smith, B.Sc., Assoc.R.S.M. (London), wrote that the occurrence of splitting along the surfaces of drawn rods when treated with chemical reagents, referred to by Dr. Stead in the course of his introductory remarks, was observed by Roberts-Austen twenty-eight years ago.

It was shown and described by him at a Royal Institution Lecture.*

A hard-drawn rod or thick wire consisting of an alloy of gold, silver, and copper was touched with a solution of chloride of iron. In a few seconds the rod was shown to split in precisely the same manner as in the specimens exhibited by Dr. Stead.

Dr. Stead, in answer to written communications, wrote thanking Mr. S. W. Smith for having drawn attention to an experiment made thirty years ago by Roberts-Austen. This, however, was made upon an alloy of gold, silver and copper, and not upon brass. Judging from the evidence afforded, it appeared possible that all hard-drawn metals and alloys might be susceptible to the action of chemical reagents. Experi-ments were called for in this particular direction.

Replying to Mr. Vaughan Hughes, he thought that the paper had

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* *Proceedings of the Royal Institution*, 1886.

made it clear that the work described was mainly an attempt to get equilibrium by long heating at constant temperatures and to correlate the structure and mechanical properties of the brass after such treatment, and not to follow works practice. The temperature in the gas works' flue certainly did vary, but did not exceed the melting-point of zinc in the case referred to in the paper. Other specimens heated at a point in the flue where zinc was constantly fluid must have been heated to 430° C. and above, but, between the structure of these and the former there was little difference, except that the latter contained slightly more β. It was certain that different rates of cooling would have yielded different microstructures and mechanical properties. Slow cooling caused a great segregation of α and the diminution of β. He would refer Mr. Hughes to the research of Bengough and Hudson on Muntz metal published many years ago.

VANADIUM IN BRASS:

THE EFFECT OF VANADIUM ON THE CONSTITUTION OF BRASS CONTAINING 50–60 PER CENT. OF COPPER.*

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MANY of the more important of the copper-zinc alloys are those containing about 60 per cent. or less of copper in which part of the zinc is replaced by small quantities of one or more other metals, such as iron, manganese, and aluminium. The number of such special brasses is now increased by those included among the alloys called vanadium bronzes, in which cupro-vanadium is used as one of the ingredients. The actual effect of vanadium in alloys of this kind does not appear to be well known, and it was thought that it would be useful, before attempting to investigate the general effect of vanadium on the properties of brass, to ascertain what, if any, were the changes brought about by small quantities of vanadium in the constitution and structure of those alloys of copper and zinc which contain between 50 and 60 per cent. of copper. The authors were also led to make such a preliminary study of the influence of vanadium by the observation of Carpenter † that not more than 1 per cent. of vanadium was able to effect the resolution of the β constituent of the copper-zinc alloys into α and γ in the case of a cast alloy containing 51·25 per cent. of copper.

The effect of vanadium on the mechanical properties of brass alloys has been dealt with by G. L. Norris,‡ who gives the results of tests on Muntz metal and manganese bronze with and without the addition of vanadium. He obtained comparatively higher tensile strengths with the alloys containing vanadium, although in the case of manganese bronze this

was at the expense of reduced ductility. The amount of vanadium present was stated to be a trace in the case of the Muntz metal, and 0·03 per cent. in the case of the manganese bronze.

Method of making the Alloys used in the Research.

Attempts were made at first to prepare brasses containing vanadium by using commercial cupro-vanadium. Samples of cupro-vanadium were obtained from two sources—from an English and a German firm respectively—and on analysis the composition was found to be as follows :—

	English.	German.
	Per Cent.	Per Cent.
Copper	51·2	47·0
Vanadium	12·0	27·2
Aluminium. . . .	25·7	19·1
Iron	5·9	4·5
Silicon	1·0	2·5

It will be noticed that in both cases large percentages of aluminium and iron are present, and it was found impossible to prepare from these materials any alloys free from important quantities of impurities. The greater part of the aluminium could be removed by oxidation, but the last 1 per cent. or so was only oxidized at the expense of much of the vanadium, while the passage of the iron into the brass could not be avoided. The presence of either of these metals was undesirable for the purposes of the research, and other means were therefore adopted to prepare copper-zinc-vanadium alloys free from iron and aluminium. Some of the alloys made from commercial cupro-vanadium were examined, and they are referred to when the results are described.

In making the pure vanadium brasses, vanadic acid was used as the source of vanadium, the following method being adopted as a result of preliminary experiments : Copper was first melted, and then vanadic acid mixed with a weighed excess of powdered aluminium was slowly stirred in together

with fluxes containing cryolite. Next the excess of aluminium was oxidized by the addition of an amount of copper oxide calculated from previous experience. After allowing the metal to cool somewhat, the slag was removed from the surface and the zinc stirred in. The brass so made was cast into a small cylindrical mould.

THERMAL EXAMINATION OF THE ALLOYS.

Cooling and heating curves were taken, using a platinum, platinum-rhodium thermocouple and potentiometer, the cold junction of the thermocouple being kept at 0° C. In the
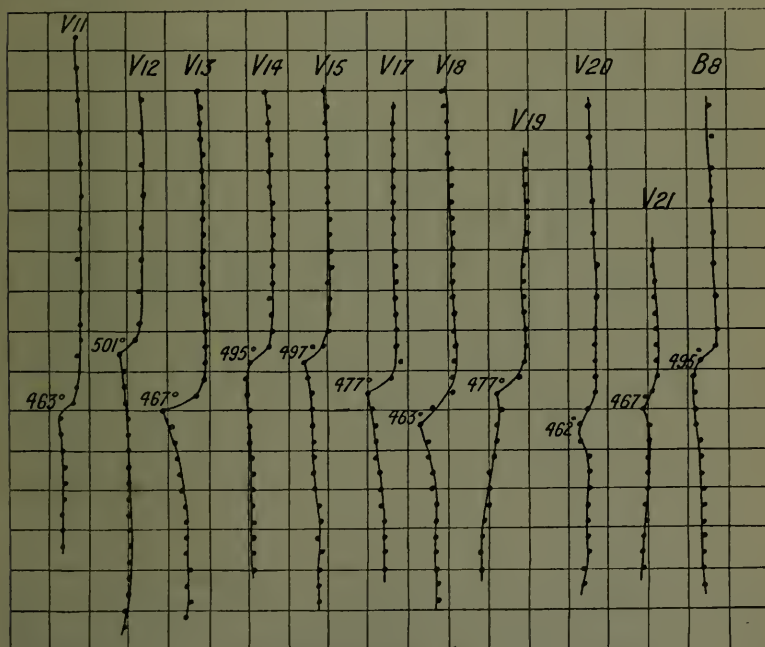
DIAGRAM I.

case of several of the earlier alloys, complete cooling curves from the liquid state were taken, but with most of the alloys the metal was cast. The ingot was then drilled down the centre with a $\frac{3}{16}$-inch drill, and the thermocouple inserted in

the hole and plugged with asbestos. Heating and cooling curves were then taken within the range 200°–650° C.

On Diagrams I. and II. will be found reproductions of the heating and cooling curves of the " pure " vanadium brasses over the range of temperature 650°–250° C. The composition of these brasses is given in Table III., together with the mean temperature (that is, the mean temperature obtained
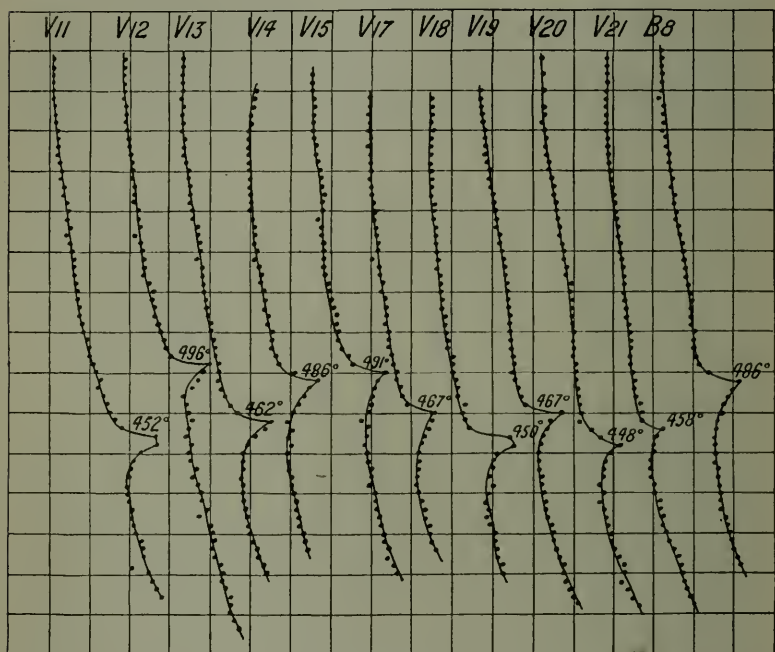
DIAGRAM II.

from the heating and cooling curves) in each case of the critical point due to the β constituent. The temperatures of the critical points shown in the heating and cooling curves (Diagrams I. and II.) have been plotted on a curve (Diagram III.) in which the temperatures are ordinates and the percentages of vanadium are abscissæ. The alloys containing some aluminium (V12, V13, V14, B8) are represented by the points marked ⊙. B8 is a similar kind of brass containing 0·9 per cent. of aluminium, but without vanadium.
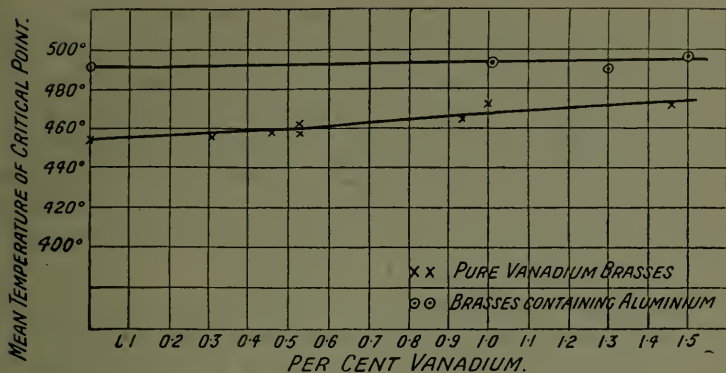
DIAGRAM III.
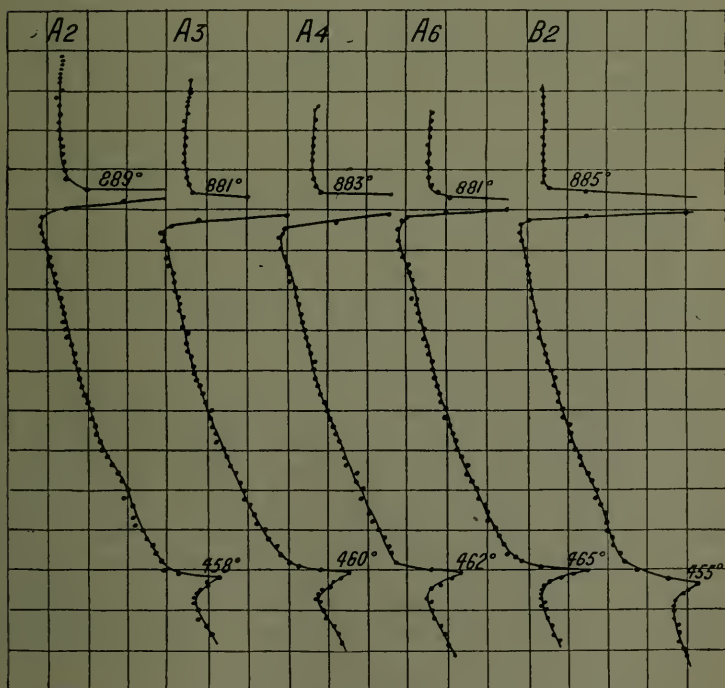
DIAGRAM IV.

It will be seen that in all the alloys containing appreciable quantities of aluminium the temperature of the critical point is about 490° C., and is independent of the vanadium present. In those brasses free from aluminium the temperature of the inversion rises very slightly with increasing vanadium, but it does not exceed 470° C. with 1·5 per cent. of vanadium. Thus vanadium does not appear to affect the critical point to any marked extent, but the presence of small quantities of aluminium raises it distinctly.   This effect of aluminium has been observed by Carpenter and Edwards.*

Heating and cooling curves over the range 300°–550° C. were also obtained with four brasses made from a commercial cupro-vanadium, most of the aluminium being eliminated by oxidation.   Particular notice was taken of the temperature of the 470° C. inversion, and the mean temperature was found in all cases to have been raised, the higher the percentage of vanadium and aluminium, the more marked being the rise. In Diagram IV. are given the cooling curves from the liquid down to about 300° C. for four brasses containing only a trace of vanadium.

MICROSCOPIC EXAMINATION.

In their equilibrium diagram of the copper-zinc series Carpenter and Edwards † place the composition of the $\alpha + \gamma$ eutectoid at about 52·5 per cent. of copper, that is, at the mean composition of Shepherd's pure β alloys.   Carpenter ‡ also shows that the structural resolution of the β into α and γ in pure brasses only takes place with great difficulty after prolonged annealing, and he further states § that certain metals, notably vanadium, bring about this structural change with comparative ease when present in the alloy in relatively small amounts.   The quantity of vanadium which, it was stated, was sufficient to give a cast alloy consisting of α and γ was not more than 1 per cent.   If this be correct, vanadium, even in very small quantities, might be an undesirable ingre-

* *International Journal of Metallography*, 1912, vol. ii. p. 209.
† *Journal of the Institute of Metals*, 1911, No. 1, p. 127.
‡ *Ibid.*, 1912, No. 1, p. 70.   § *Ibid.*, 1912, No. 2, p. 59.

dient of brasses containing a large proportion of the β constituent. As will be seen from the following account of the microstructure of the slowly cooled and also of the annealed vanadium brasses, no evidence was obtained that vanadium assists the structural resolution of β into α and γ.

Slowly-cooled Alloys.—The specimens used for microscopic examination were cut from ingots used in the thermal examination of the alloys, and had consequently been slowly cooled from about 650° C. The structures observed were as follows :—

β-Alloys.—Alloys V17 (copper 54·6 per cent., vanadium 1·0 per cent.) and V18 (copper 53·9 per cent., vanadium 0·53 per cent.) consisted entirely of the β constituent, except for some hard, blue, slag-like inclusions, to which reference will be made later. A typical structure is illustrated by Photo No. 11, Plate IX.

α + β Alloys.—Alloy V11 (copper 55·7 per cent., vanadium 0·46 per cent.) consisted of β with some α (see Photo No. 7, Plate IX.). Alloys V20 (copper 57·9 per cent., vanadium 0·31 per cent., Photo No. 2, Plate VIII.) and V21 (copper 60·2 per cent., vanadium 0·53 per cent., Photo No. 1, Plate VIII.) also showed an ordinary $\alpha + \beta$ structure, although perhaps the proportion of β appeared to be slightly higher than would be expected in pure brasses with the same percentages of copper.

β + γ Alloys.—Alloys V13 (copper 50·1 per cent., vanadium 0·94 per cent.) and V19 (copper 51·3 per cent., vanadium 1·46 per cent., Photo No. 3, Plate VIII.) consisted of β with a small amount of γ, the proportion of the latter being slightly in excess of that found in a corresponding pure brass.

The general conclusion drawn from the study of the microstructure of these alloys was that vanadium to the extent of about 1 per cent. has little influence on the relative proportions of α and β, or of β and γ. The vanadium appears to replace rather more than an equal weight of zinc, but has no tendency to cause a resolution of the β into α and γ in cast or slowly cooled alloys.

Annealed Alloys.—Specimens of alloys V11, V12, V13, and V17, together with a specimen of alloy F3 (a pure copper-zinc

alloy with 55·4 per cent. of copper), were annealed at 445° C. in an atmosphere of sulphur vapour.* The specimens were each sealed in a thin glass bulb, and these bulbs then sealed in pairs in larger tubes, which were suspended in glass boiling-flasks. The flasks contained sulphur, which was kept boiling at such a rate that the sulphur vapour condensed just above the level of the specimens in the suspended tubes. The specimens were removed and examined at intervals, the effects of annealing being in each case as follows :—

V17.—This consisted of β only, and showed no change even at the end of 9 weeks (see Photo No. 12, Plate IX.).

V13.—This originally consisted of β with a little γ (see Photo No. 4, Plate VIII.). After 14 days' annealing it appeared to contain slightly less γ (Photo No. 5, Plate VIII.). No further change was observed after 9 weeks. The apparent small decrease in the amount of the γ may be due to slight volatilization of zinc, although no crack was observed in the glass bulb in which the specimen was annealed. Photo No. 6, Plate VIII., shows the structure after 9 weeks.

V11.—The structure of the slowly cooled alloy was β with some α (Photo No. 7, Plate IX.). After 7 days' annealing an increase in the amount of α was noticed, this further growth appearing in a finely divided condition (see Photo No. 8, Plate IX.). After another 7 days (Photo No. 9, Plate IX.) the "second growth" of α showed signs of coalescing, and a further coalescence of the α was the only change in structure observed after a total annealing of 9 weeks (Photo No. 10, Plate IX.). The β did not appear to be in any way changed at any stage of the annealing.

V12.—The original structure was β with a few small crystals of γ (Photo No. 13, Plate X.). Except that, as in the case of alloy V13, the amount of γ appeared to be somewhat less, annealing has practically no effect on the structure, and no change in the β could be seen after 9 weeks' annealing (Photo No. 14, Plate X.).

F3 (*Pure Brass*).—This consisted in the original condition —the specimen was cut from a forged bar—of β almost free

* This method of annealing at constant temperature was used by Carpenter, and described by him in this Journal (1912, No. 1, p. 70).

from a (Photo No. 15, Plate X.).   After 3 days' annealing the polished section showed the growth of some small crystals of a (Photo No. 16, Plate X.).   On further annealing the small a crystals coalesced into a small number of larger ones. Photo No. 17, Plate X., shows the structure after $5\frac{1}{2}$ weeks' annealing at 447° C., and Photo No. 18, Plate X., shows the result of a total annealing of 11 weeks.

It will be seen from the photographs that in none of the alloys—not even in V12 with 1·5 per cent. of vanadium and 0·66 per cent. of aluminium—has the β constituent been split up into visible a and γ by prolonged annealing at a temperature a little below the inversion temperature, though the conditions were, as far as could be obtained, favourable for this resolution.   The alloys were also examined at high magnifications, and the β in every case appeared to be quite homogeneous.

In some of the photographs shown, *e.g.* Nos. 3 and 12, there will be noticed irregular dark patches.   Actually these appeared of a dark, bluish colour.   This substance was first thought to be included slag or alumina, and many attempts were made to prevent its presence in the brasses.   As a result of investigations, it was concluded that it was an oxidized product of the vanadium which became entangled in the molten alloy.   Efforts to separate the substance by chemical means were not successful.   No such particles could be obtained in any alloy unless vanadium was present, although attempts were made to include particles of alumina formed by the reduction of copper oxide.   The alloys with less than about 0·5 per cent. of vanadium were free from this slag-like substance, or contained only a little; but no brasses with a higher percentage were obtained without it.   It is possible that the excess of vanadium over 0·5 per cent. in any brass did not exist in solid solution, but in this oxidized form.

General Conclusions.

1. The critical point occurring at about 460° C. in brasses containing the β phase is only slightly affected by vanadium, 1 per cent. raising it not more than 10° C.

2. The usual structure of brasses containing between 50 and 60 per cent. of copper is not greatly modified by the presence of small quantities of vanadium, although alloys containing more than about 0·5 per cent. of vanadium were observed to contain some hard, bluish, slag-like inclusions.

3. Vanadium to the extent of at least 1 per cent. appears to have no influence on the structural stability of the β constituent of the copper-zinc alloys, and if any structural resolution of β into α and γ follows the addition of cupro-vanadium to brass, the result probably is due rather to the relatively large amounts of aluminium usually present in commercial samples than to the small percentage of vanadium remaining in the finished brass.

APPENDIX.

Analysis of the Brasses.—The analysis of the brasses made in the course of this research was a matter of considerable importance, and one on which some time was spent before reliable methods were arrived at.

In replying to the discussion on his paper,* " The Effect of other Metals on the Structure of the β Constituent in Copper-zinc Alloys," Professor Carpenter said that he did not directly determine the vanadium in his vanadium-brass, and that he was not aware that there was any good method in existence by which it could be directly determined in such alloys. It was therefore thought that a brief description of the methods used might be of interest.

Determination of the Vanadium.—The vanadium was obtained in dilute sulphuric acid solution, together with the zinc and any iron and aluminium, the copper having been separated as sulphide. The vanadium was reduced to the state of hypovanadate by sulphurous acid, the iron at the same time being reduced to the ferrous condition. The excess of sulphurous acid was removed by boiling whilst passing a stream of carbon dioxide through the solution.

* *Journal of the Institute of Metals*, 1912, No. 2, p. 59.

PLATE VIII

No. 1.—Alloy V21. Slowly cooled.
(Cu 55·7 per cent., V 0·46 per cent.)
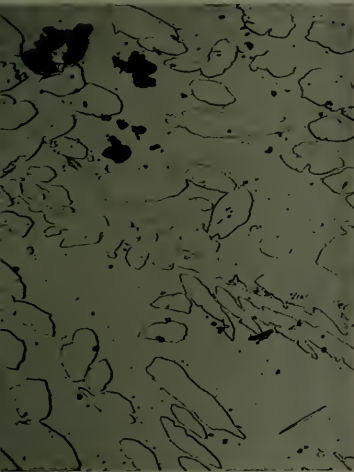
No. 2.—Alloy V20. Slowly cooled.
(Cu 57·9 per cent., V 0·31 per cent.)
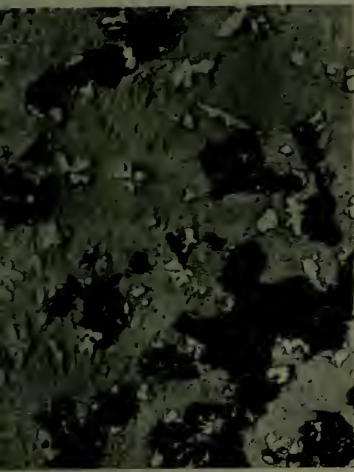
No. 3.—Alloy V19. Slowly cooled.
(Cu 51·3 per cent., V 1·46 per cent.)
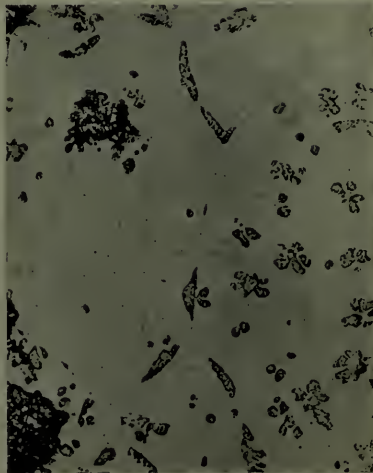
No. 4.—Alloy V13. Slowly cooled.
(Cu 50·1 per cent., V 0·94 per cent.)

No. 5.—Alloy V13.
Annealed for 14 days at 447° C.
(In this case the β has been stained black.)
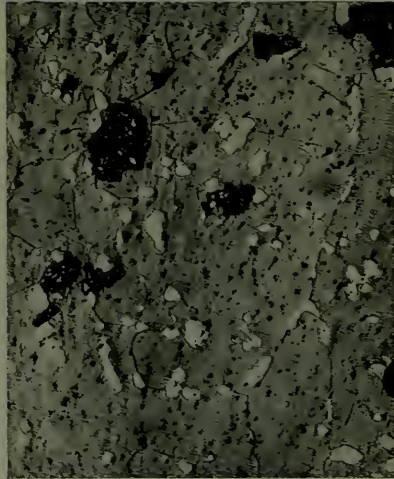
No. 6.—Alloy V13.
Annealed for 9 weeks at 447° C.

Photographs all taken at a uniform magnification of 100 diameters, and in all cases the specimens were etched with ammonia, using a polish attack.

PLATE IX

No. 7.—Alloy V11.
(Cu 55·7 per cent., V10·46 per cent.) Slowly cooled.
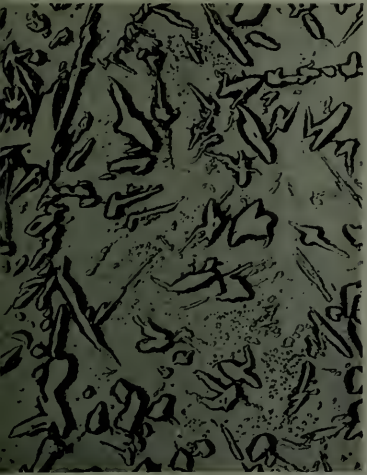
No. 8.—Alloy V11.
Annealed for 7 days at 447° C.

No. 9.—Alloy V11.
Annealed for 14 days at 447° C.
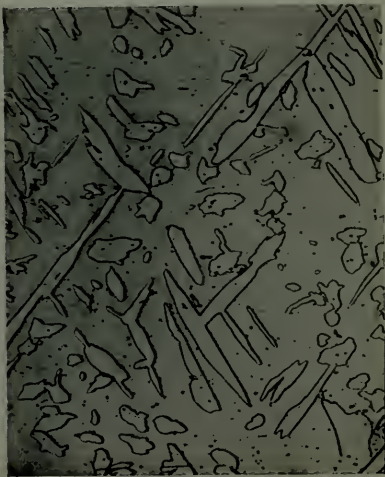
No. 10.—Alloy V11.
Annealed for 9 weeks at 447° C.
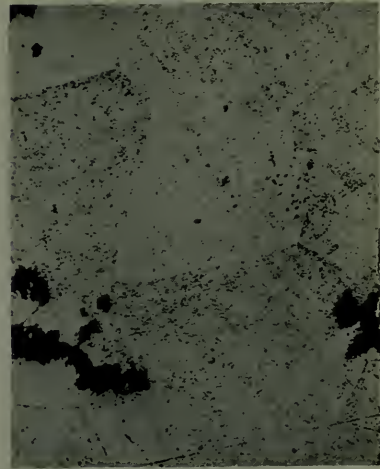
No. 11.—Alloy V17.
(Cu 54·6 per cent., V 1·0 per cent.) Slowly cooled.

No. 12.—Alloy V17.
Annealed for 9 weeks at 447° C.

Photographs all taken at a uniform magnification of 100 diameters, and in all cases the specimens were etched with ammonia, using a polish attack.

PLATE X

No. 13.—Alloy V12.
(Cu 53·2 per cent., V 1·5 per cent., Al 0·66 per cent.)
Slowly cooled.

No. 14.—Alloy V12.
Annealed for 9 weeks at 447° C.
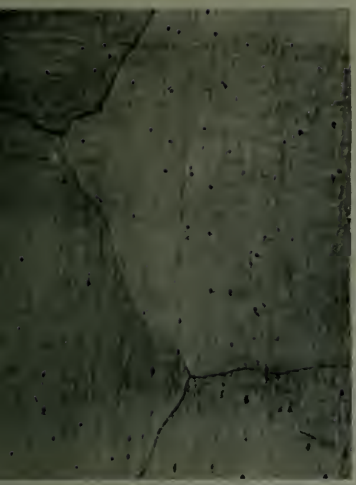
No. 15.—Alloy F3.
(Cu 55·4 per cent., Zinc 44·6 per cent.) As forged.
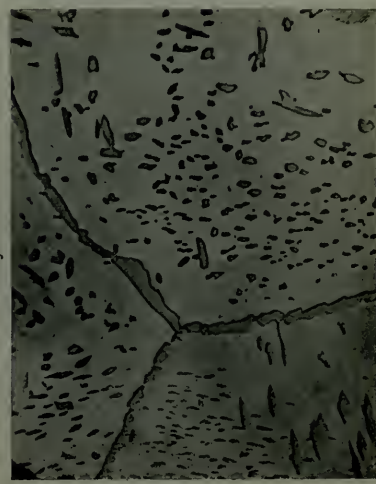
No. 16.—Alloy F3.
Annealed for 3 days at 447° C.

No. 17.—Alloy F3.
Annealed for 38 days at 447° C.
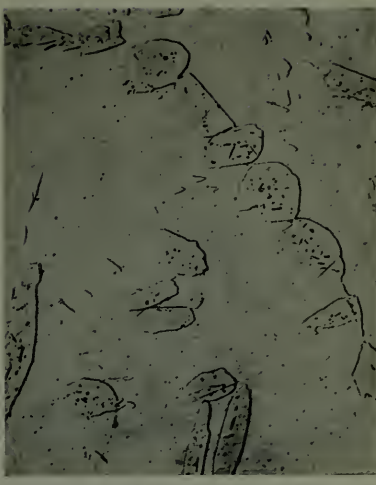
No. 18.—Alloy F3.
Annealed for 11 weeks at 447° C.

Photographs all taken at a uniform magnification of 100 diameters, and in all cases the specimens were etched with ammonia, using a polish attack.

The hot solution was titrated to a permanent pink colour with standard potassium permanganate solution. The permanganate used in this titration was taken up in oxidizing the vanadium and any iron that was present.

The value of the vanadium alone was next obtained by adding standard ferrous ammonium sulphate to the just pink solution until the presence of ferrous ions was indicated on mixing a drop of the solution with a drop of a fresh dilute solution of potassium ferricyanide.

The titrations are best carried out with the solutions at about 80° C.; they should not be allowed to fall below 60° C.

The presence of traces of hydrochloric acid or a chloride must be avoided, as the permanganate readily attacks these in the hot solution.

THE FOLLOWING IS A LIST OF REFERENCES RELATING TO THE ANALYTICAL METHOD USED.

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GRAHAM EDGAR, "Volumetric Estimation of Iron and Vanadium, using SO_2 and Amalgamated Zinc as Reducing Agents." *American Journal of Science* (IV.), vol. xxvi. p. 79.

W. CLARK, "Volumetric Estimation of Vanadium, using Ferrous Ammonium Sulphate and Potassium Bichromate." *Metallurgical and Chemical Engineering*, 1913, p. 195.

N. CZAKO, "Estimation of Vanadium in Aluminium Alloys by titration with Permanganate." *Comptes Rendus*, 1913, vol. clvi. p. 140.

DEISS and LEYSAHT, "Ether Separation of Iron and Vanadium." *Journal of the Society of Chemical Industry*, 1911, p. 1090.

MÜLLER and DIEFENTHÄLER, "Volumetric Estimation of Iron and Vanadium, using Permanganate and reducing (i.) with Alcohol and Hydrochloric Acid, (ii.) with SO_2." *Zeitung für anorganische Chemie*, 1911, p. 243 (Abstract, *Journal of the Society of Chemical Industry*, 1911, p. 1017).

TABLE I.—*Alloys made from Purified Cupro-Vanadium and Cooling Curves of which are given in Diagram IV.*

Mark.	Copper, per Cent.	Vanadium, per Cent. Found.	Vanadium, per Cent. Calculated.	Melting-point, Degrees C.	Critical Point, Degrees C.	Remarks.
A2	52·1	Trace	1·5	889	458	The cupro-vanadium contained 0·18 per cent. of aluminium.
A3	52·6	,,	0·9	881	450	
A4	52·5	,,	0·5	883	462	The cupro-vanadium contained 0·22 per cent. of aluminium.
A6	52·6	,,	0·9	881	465	

TABLE II.—*Alloys made from Commercial Cupro-Vanadium which were Examined Thermally.*

Mark.	Copper, per Cent.	Vanadium, per Cent.	Aluminium, per Cent.	Iron, per Cent.	Mean Temperature of Critical Point, Degrees C.	Microstructure.
A15	50·6	2·70	1·50	3·40	538	$\beta+\gamma$
A16	55·0	0·62	1·01	1·19	496	β
A17	48·0	3·06	1·45	2·41	527	$\beta+\gamma$
A18	50·4	0·76	Trace	1·00	480	$\beta+\gamma$

TABLE III.—*Alloys ("Pure" Vanadium Brasses) made from Vanadic Acid.*

Mark.	Copper, per Cent.	Zinc, per Cent.	Vanadium, per Cent.	Aluminium, per Cent.	Iron, per Cent.	Mean Temperature of Critical Point, Deg. C.	Microstructure.
V11	55·7	43·8	0·46	Trace	Trace	457	$\beta+\alpha$
V13	50·1	48·9	0·94	"	"	465	$\beta+\gamma$
V17	54·6	44·2	1·00	0·13	"	472	β
V18	53·9	45·4	0·53	0·15	"	457	β
V19	51·3	46·5	1·46	Trace	0·63	472	$\beta+\gamma$
V20	57·9	41·7	0·31	Nil	Trace	456	$\beta+\alpha$
V21	60·2	39·2	0·53	Trace	"	462	$\beta+\alpha$
V12	53·2	44·6	1·50	0·66	"	496	$\beta+\gamma$
V14	52·9	45·1	1·30	0·63	"	490	β
V15	52·4	45·8	1·09	0·67	"	493	β
B8	51·7	47·4	Nil	0·92	Nil	491	$\beta+\gamma$
B2	52·5	47·5	"	Nil	"	455	β

DISCUSSION.

Professor A. K. HUNTINGTON, Assoc.R.S.M. (Past-President), in open-ing the discussion, said that the paper thoroughly confirmed the convic-tion which he himself held on the subject, namely, that vanadium was not serving any particular good purpose in brass. In the discussion on Professor Carpenter's paper on the " Effect of other Metals on the Struc-ture of the β Constituent in Copper-Zinc Alloys," * he asked " whether aluminium was looked for in the vanadium alloy." He had found in examining some vanadium that there was a lot of aluminium present, and he had come to the conclusion that it was that which was probably operating in Professor Carpenter's experiment. It was very satisfactory to have that very clearly proved by the carefully carried out research of Messrs. Dunn and Hudson. They also made it apparent that the sup-posed change into $\alpha + \gamma$ was very doubtful. He was of the opinion that a little more research was desirable on that subject also.

Dr. G. D. BENGOUGH, M.A. (Liverpool), said that he had made a few experiments on the effects of vanadium in brass some years ago, but did not continue with the work very far; and now that he read about the difficulties which had been encountered by the authors he was uncom-monly glad that he had not pushed on with it, as the work was evidently very difficult to carry out in a satisfactory manner. He thought the authors deserved great credit for carrying it out as they had done. When he had been at work on the subject, Professors Carpenter and Edwards had not read their paper on the change from β to $\alpha + \gamma$, so that the work did not at that time seem to be of any urgent importance; but since Professor Carpenter's work on the effect of vanadium on that change, he thought the matter deserved to be threshed out in some considerable detail. It was greatly to be regretted that Messrs. Carpenter and Edwards were not present that day to speak on the paper, because when they had read their papers before the Institute on the question, he (the speaker) was about the only member who supported their views. There-fore, for want of a better defender, he would like to make a few remarks about the change. He knew he could not fulfil the post of defender like either Professor Carpenter or Dr. Edwards, and he would only do so in their default.

Turning to page 157 of the paper, the authors said that there was no evidence that vanadium assisted the structural resolution of β into $\alpha + \gamma$. He thought one possible criticism which could be made upon the authors' experiments was as follows: Was the vanadium in those alloys in solid solution at all, or was it entirely contained in those slag-like masses? If it were entirely contained in those slag-like masses, whatever they were, of course it would not have any effect on the resolution of β into $\alpha + \gamma$. Eight of the microphotographs given by the authors showed those inclusions, and he would like to ask the authors whether all the specimens showed those slag-like masses, and whether they had

really satisfied themselves that there was any vanadium in solid solution in either the β or α. As far as he remembered the photographs published by Carpenter did not show those masses at all, and this constituted a very important difference between the two sets of microphotographs. He would like Mr. Hudson to give a little more light on that point.

Another matter which might be raised was the exact method of etching used to distinguish between α, β, and γ. That was really what the whole controversy turned on. If Professor Carpenter were wrong it simply meant that his method of etching had misled him into confusing the three phases, and the point therefore really turned on the question of etching β and γ. He would therefore like to ask the authors for very precise details as to the exact method of etching they used. It seemed to him that it might almost be a case for colour photography, a subject in which he was very much interested. It seemed to him that the microphotographs in monotone did not enable anyone who had not seen the specimens to distinguish between β and γ, since the latter did not always show its characteristic shape. He would like to ask if the blue slag-like inclusions which the authors referred to contained γ and whether they were not some sort of compound or solid solution of γ containing vanadium.

With regard to the microphotographs shown on Plate X., he desired to ask whether the small dots shown in photographs 14 and 15 were γ. He took it they were.

Mr. G. A. BOEDDICKER (Vice-President) said that, as far as he was able to judge, the paper was only of theoretical interest, and as such it seemed to him to give a negative result. However, even a negative result was very useful, because it might prevent other people going into the same matter. He himself was more interested in the practical point, and though the theoretical result might be negative, practically there might be some effect of vanadium on brass, and he thought it was very much to be regretted that the authors did not give any physical tests. That small enclosures of metals had very strong mechanical effects on tensile strength, &c., was very well proved by the presence of lead in brass. He thought the physical test especially important because metals like vanadium and a few other rarer substances were always very largely advertised, and the mechanical properties of " vanadium " and other brasses should be investigated by competent men like the authors to show once and for all whether the alloys were of any use.

Dr. C. H. DESCH (Glasgow) suggested that the blue slag-like constituent might be one of the lower oxides of vanadium. It was well known that the lower oxides of vanadium were extremely metallic in character, and might be easily mistaken for a metal. In fact, when vanadium was first discovered, its properties would not fit in with a place in the periodic table. Eventually Roscoe showed that the material which had been examined and studied, and had been supposed to be metallic vanadium, was not a metal at all but an oxide. Another thing

which pointed to the same conclusion was that if vanadium-copper were polished, a certain number of dendrites—not a very large proportion—of a very hard, bright blue material would stand out in relief.   He had not seen the specimens of Mr. Hudson, so he could not say whether the blue appearance was the same, but he would suggest that it might be due to the presence of oxide.   In the vanadium-copper he imagined the vanadium and copper would form a solid solution together, and the constituent in excess was probably an oxide.   Another possibility was that it might contain nitrogen, as vanadium owed its special qualities as a scavenging metal to the fact that it removed not only oxygen but nitrogen from alloys.

Professor T. TURNER, M.Sc. (Vice-President and Honorary Treasurer), said that he was glad that the authors had been able to present to the Institute, as a result of their researches, so coherent a conclusion as that which appeared in the paper.   He had had the opportunity of seeing the work done.   After working very strenuously for some two or three months, the authors had not arrived at any conclusion at all, and it seemed almost as though the research would have to be abandoned on account of the difficulty of obtaining pure materials.   It must not be supposed that it was suggested that commercial cupro-vanadium was necessarily of no value ; it might be a very valuable material to the brass-founder.   All that was said by the authors was that the commercial cupro-vanadium had other materials present which might account for the good effects which were seen, apart altogether from the vanadium.   He had pointed out from the first the advantage there would be in making physical tests, if possible ; and the original plan of work included a series of physical tests, as would be natural under such circumstances.   So long as it was intended to use commercial materials which could be bought in reasonable quantity, the carrying out of a series of physical tests could be contemplated ; but when vanadium oxide had to be bought at a somewhat high price, and when the vanadium had to be reduced, and the excess of aluminium removed by reactions somewhat difficult to regulate, it would be seen that all the authors could do in the circumstances was to prepare sufficient material for what might be called the more scientific side of the investigation.   If, however, there was anybody who could supply the authors with either pure vanadium, or with pure cupro-vanadium, with which to carry on the experiments, he was quite sure that Mr. Hudson and the students in his own department would be most willing to carry their researches further.

Mr. ARNOLD PHILIP, B.Sc., Assoc.R.S.M. (Member of Council), desired to say with regard to the method of the chemical determination of vanadium which the authors had used, that he had carried out a series of analyses by this process on solutions of brass to which vanadium had been added.   The method was, with slight modifications, the same as that generally used for determining vanadium in steel.   He obtained the following results :—

Vanadium Present as Sodium Vanadate. Per Cent.	Vanadium found by the Author's Process. Per Cent.
0·54	0·56
1·07	1·12
1·61	1·64
2·15	2·16

The method therefore gave results which showed a variation of from about 0·5 to 4 per cent. calculated on the amount of vanadium present. This was a very satisfactory accuracy, and about equal to that found in determining similar percentages of iron.

Mr. DUNN, in reply, said that Dr. Bengough had suggested the possibility of all the vanadium in the brass existing in the form of the separated slag-like particles and of none being actually in solution in the alloy, but Mr. Hudson and himself had examined alloys with up to 0·5 per cent. vanadium in which this slag-like constituent did not appear at all. Photographs Nos. 7, 8, 9, and 10 showed one of those with 0·46 per cent. vanadium.

Dr. Desch had mentioned the hard blue dendrites which he had observed in cupro-vanadium ; a similar structure had been obtained by the authors on polishing a section of their cupro-vanadium. He agreed with Dr. Desch that it was possibly an oxide or solution of oxide and metal. He would leave Mr. Hudson to deal with other points raised in the discussion.

Mr. HUDSON, also replying to the discussion, said that he felt that he ought perhaps to make some apology for the very academic character of their paper, but he thought the point dealt with was of some importance and required clearing up. He hoped that in the near future they would be able to study the mechanical and other properties of the vanadium brasses, but at present, as pointed out by Professor Turner, the difficulty and expense of making the pure alloys in sufficiently large quantities with such material as pure vanadic oxide was almost prohibitive. Dr. Bengough had asked for some detailed account of the method of etching adopted. The method was as follows : a piece of parchment 4 or 5 inches long and about 2 inches wide was thoroughly soaked in water and spread on a smooth block of wood. A few drops of ammonia and a small quantity of freshly prepared magnesia were then placed on the parchment and the specimen rubbed on it gently for a few seconds. The specimen was then washed in water, quickly dried on soft linen, and examined. The polish attack was repeated if necessary until the constituents were obtained sharply outlined and, as far as possible, free from any stain. When α and β were present side by side there was a very distinct difference in the colour, α being yellow with a somewhat pinkish tinge, and β a bright yellow with a slight greenish tinge. There was no difficulty in distinguishing them side by side. In the case of β and γ, the light blue colour of the γ was quite distinct, apart altogether from its form. The colour of the blue slag-like inclusions was a brighter blue than the γ, and he did not think there could be any possibility of

missing the presence of γ in those slag masses.   He remembered in some cases seeing crystallites of γ just included inside the slag masses, and they could be easily distinguished.   So in the other cases he thought it was very unlikely that they would be misled in that direction.

With reference to the very small dot in the photographs to which Dr. Bengough had referred, many of those dots were very small particles of γ, but in a few cases they were due to minute holes.   Perfectly sound alloys throughout were not always obtainable, and there was a possibility of getting some minute holes scattered throughout, probably due to gas.

He was glad to hear from Mr. Philip that the general method of analysis adopted had proved to be accurate.

He would like to express his regret that Professor Carpenter was not present to criticize the paper.

THE INFLUENCE OF NICKEL ON SOME COPPER-ALUMINIUM ALLOYS.*

By Professor A. A. READ, M.Met., F.I.C., and R. H. GREAVES, M.Sc.
(University College, Cardiff).

ALTHOUGH alloys containing copper, nickel, and aluminium have been used commercially from time to time, no systematic study of their properties appears to have been published. The authors therefore undertook to investigate the influence of nickel, chiefly on two typical commercial copper-aluminium alloys, namely, those containing 5 and 10 per cent. of aluminium respectively.

Guillet † mentions a number of complex aluminium bronzes containing nickel, but as the metals all contained comparatively large and varying amounts of iron and silicon, it is impossible to deduce from the tests given the exact influence of the nickel on their mechanical properties.

Alloys with from 6 to 12 per cent. of aluminium and about 20 to 30 per cent. of nickel have been prepared by Andrews,‡ who found them hard, fine grained, and of great strength.

Copper-nickel-aluminium alloys with upwards of 20 per cent. of nickel, and varying amounts of aluminium, have been introduced under such names as " Aluminium Silver," " Minargent," &c., as substitutes for the finer grades of German silver, as they have a beautiful white colour, and take a high polish.§ Some of these contain up to 7 per cent. of aluminium, but more often they are really copper-nickel alloys deoxidized by means of aluminium, only a very small quantity of which remains in the finished metal.

The three binary systems which are involved in these alloys, however, have received much more attention.

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* Read at Annual General Meeting, London, March 18, 1914.
† Guillet, ''Les Alliages Métalliques,'' 1906, p. 748.
‡ Andrews, *Journal of the American Chemical Society*, 1894, p. 486.
§ Richards, ''Aluminium, its Metallurgy and Alloys,'' 1896, pp. 511–516. Guillet, '' Les Alliages Métalliques,'' 1906, p. 919; Vickers, *Metal Industry*, 1909, vol. i. p. 49.

The report of Carpenter and Edwards * furnishes a very complete and detailed account of the alloys of copper and aluminium.

With regard to copper-nickel alloys, Heycock and Neville † showed that the addition of nickel to copper resulted in an immediate rise in melting-point, but their study of the alloys included only those containing a small quantity of nickel. Gautier ‡ investigated the whole series of alloys, and came to the conclusion that a compound CuNi was formed, but this has since been shown to be incorrect by Guertler and Tammann.§ They found that the freezing-point curve is continuous, rising almost though not quite in a straight line from the melting-point of copper (1083° C.) to that of nickel (1451° C.), and that at every point mixed crystals separate ; while Vigouroux ‖ also concluded from the chemical behaviour of the alloys that no compound of these metals is formed.

The constitution of the nickel-aluminium alloys has been investigated by Gwyer,¶ who found that three compounds were formed, namely, NiAl (m.p. 1640° C), $NiAl_2$ and $NiAl_3$. Robin ** gives a micrograph of the alloy containing 5 per cent. of nickel and 95 per cent. of aluminium, showing needles to which he assigns the formula $NiAl_6$; and he further states that this constituent occurs in the alloy composed of 25 per cent. of nickel, 18 per cent. of copper, and 57 per cent. of aluminium.

Materials Used.

For the purpose of carrying out this research the following materials were procured :—

Electrolytic or cathode copper of very high purity from Messrs. Vivian & Sons, Swansea.

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* " Eighth Report, Alloys Research." *Proceedings of the Institution of Mechanical Engineers*, 1907.

† *Philosophical Transactions*, 1897, vol. clxxxix. p. 69.

‡ *Comptes Rendus*, 1896, vol. cxxiii. pp. 172–174.

§ *Zeitschrift für anorganische Chemie*, 1907, vol lii. p. 25.

‖ *Comptes Rendus*, 1909, vol. cxlix. p. 1378.

¶ *Zeitschrift für anorganische Chemie*, 1908, vol. lvii. p. 113.

** Robin, " Traité de Métallographie," 1911, p. 344.

Shot nickel containing at least 99·8 per cent. of nickel from the Mond Nickel Co.; this, on analysis, gave:—

								Per Cent.
Silicon	.	.	.	.	.	.	.	0·01
Iron .	.	.	.	.	.	.	.	0·04

Aluminium of guaranteed purity, 99·5 per cent., from British Aluminium Company; this was found on analysis to contain:—

								Per Cent.
Silicon	.	.	.	.	.	.	.	0·17
Iron .	.	.	.	.	.	.	.	0·18
Sodium	.	.	.	.	.	.	.	0·05

The nickel was introduced into the alloys in the form of 50 per cent. cupro-nickel. The whole of the nickel required was placed in a Salamander crucible with two or three layers of copper towards the top, and covered with lump charcoal. The crucible was heated in a coke wind furnace, and the remaining copper added as the charge sank down in the pot. Much quicker melting was attained by this method than by charging alternate equal layers of nickel and copper, and so reserving some nickel as well as copper to add as the charge melted down. The molten metal was well stirred with a graphite rod, and poured into cylindrical chill moulds.

Methods of Analysis.

Estimation of Nickel.—Drillings or turnings were dissolved in nitric acid and evaporated to dryness. The mass was taken up in hydrochloric acid, and the solution evaporated until the chloride began to crystallize out. After adding acetic acid and diluting with hot water, the copper was reduced to the cuprous state by means of sulphurous acid. The copper was then precipitated with a solution of potassium sulphocyanide, and the cuprous sulphocyanide filtered off, fractional filtration being employed to avoid washing the precipitate. The nickel in the filtrate was estimated by titrating in the usual way, with a standard solution of potassium cyanide, tartaric acid being used to prevent the precipitation of aluminium hydroxide.

Estimation of Copper.—The copper was determined by the iodine-thiosulphate method.

Estimation of Aluminium.—This has been taken by difference, which probably involves less error than a direct determination.

Preliminary Experiments.

Small trial ingots weighing about 300 grammes, containing varying amounts of copper, nickel, and aluminium, were cast in open chill moulds. The values of the relative hardness, recorded with the compositions of these ingots in Table I., were obtained by means of the Shore scleroscope, using the universal hammer.

Table I.—*Composition and Relative Hardness of the Small Ingots.*

No.	Composition.			Relative Hardness.
	Copper per Cent.	Nickel per Cent.	Aluminium per Cent.	
a	89·55	0·97	9·48	23·0
b	85·15	4·94	9·91	33·0
c	80·13	9·98	9·81	35·0
d	75·13	14·95	9·92	32·0
e	94·04	0·92	5·04	10·0
f	90·09	4·90	5·01	10·5
g	85·08	10·07	4·85	22·0
h	79·99	15·26	4·75	36·0
i	97·75	1·03	1·22	7·0
j	95·21	3·57	1·22	8·0
k	89·24	9·83	0·93	9·0
l	84·54	14·58	0·88	13·0

Colour.

The effect of nickel was in all cases to make the golden colour of the alloys paler, but its influence was much more marked in the 5 per cent. series than in the series with 10 per cent. of aluminium. Thus the alloy with 5 per cent. of aluminium and 15 per cent. of nickel showed only a slight yellow tinge, and was much whiter than the metal with the

same quantity of nickel and 10 per cent. of aluminium. The colour of the alloys with 15 per cent. of nickel was almost a silvery white, but in none of them was the characteristic golden colour of the copper - aluminium alloys entirely destroyed.

Cold Rolling Tests.

Pieces having the approximate dimensions 2·5 inches by 0·6 inch by 0·35 inch were cut for rolling. These were rolled cold with the necessary annealings, if possible, to a thickness of 0·1 inch, and then without further annealing to a strip having a thickness of 0·02 inch. In each series the conditions were made as nearly as possible the same in every case. Judged by their behaviour in the rolling test, the metals in each series stand in the following order :—

Aluminium, 1 *per Cent.*—*i*, *j*, *k*, all about equally good with very slight surface cracks ; *l*, edges slightly serrated.

Aluminium, 5 *per Cent.*—*e*, *f*, both rolled down to 0·02 inch, but were slightly rough at the edges ; *g* broke down at 0·2 inch, and *h* at 0·28 inch.

Aluminium, 10 *per Cent.*—*a* remained perfect down to 0·1 inch, but broke down on further rolling ; *b*, *c*, and *d* broke down at 0·17, 0·21, and 0·24 inch respectively, in spite of being repeatedly annealed.

Hot Forging Tests.

Small blocks of metal having the dimensions $1\frac{1}{2}$ inch by 1 inch by $\frac{3}{4}$ inch thick were forged down hot to a thickness of from 0·2 to 0·3 inch under a steam hammer. On account of the small mass of metal they sometimes required reheating, and in the case of the harder alloys were reheated several times. The results of the tests were as follows :—

Aluminium, 1 *per Cent.*—All forged without any sign of a flaw except *l*, which showed signs of cracking at the edges.

Aluminium, 5 *per Cent.*—*e* forged out perfectly, *f* and *g* showed very slight cracks, but *h* cracked badly.

Aluminium, 10 *per Cent.*—*a* and *b* remained perfect, *c* showed slight cracks at the edges, and *d* broke down in the test.

It was concluded from these observations that as regards the series containing 5 and 10 per cent. of aluminium, all the alloys with 10 per cent. or less of nickel could probably be hot rolled, while alloys which would withstand cold rolling were confined to those of the 5 per cent. series which contained not much more than 5 and certainly less than 10 per cent. of nickel. The authors were therefore in a position to be able to decide upon the composition of the ingots for the investigation, on a larger scale, of the effect of nickel on the copper-aluminium alloys containing 5 and 10 per cent. of aluminium respectively.

Melting and Casting of the Ingots.

The copper and cupro-nickel were melted together under charcoal in a Salamander crucible, heated in a coke wind furnace. When all the metal had melted and had attained a good temperature, it was well poled, and the aluminium which had been heated up almost to its melting-point was

Table II.—*Composition of the Ingots.*

No.	Copper per Cent.	Nickel per Cent.	Aluminium per Cent.
1	89·94	...	10·06
2	89·14	1·04	9·82
3	87·66	2·46	9·88
4	85·11	4·95	9·94
5	82·82	7·48	9·70
6	94·98	...	5·02
7	93·96	0·94	5·10
8	92·68	2·38	4·94
9	89·84	4·84	5·32
10	87·48	7·31	5·21

forced down into the molten metal. The aluminium at once melted and dissolved in the copper. In each case, on the addition of the aluminium, a marked rise in temperature was observed. The metal was well stirred with a graphite rod to ensure thorough mixing, the crucible was withdrawn, and the metal skimmed and teemed at as low a temperature as

possible into a circular cast-iron chill mould, following up
with fluid metal from the pot to avoid the pipe which would
be caused by shrinkage. The ingots thus cast were $2\frac{1}{4}$ inches
in diameter, 18 inches in length, and weighed about 20 lbs.
The time from charging the cold metal to teeming was about
one hour. The maximum loss of aluminium was 0·4 per
cent., the average loss being about 0·2 per cent. There was
no loss of nickel. Ten ingots were cast, and on analysis gave
the results shown in Table II.

Rolling of the Ingots.

The ingots were rolled in the presence of one of the authors
at the Fazeley Street Mills of Messrs. Charles Clifford & Son,
Birmingham, and the authors are indebted to Mr. A. H.
Wolseley, not only for his interest and advice, but for his
kindness in personally supervising the rolling operations.
The eight ingots containing nickel were all heated up to the
same temperature together and rolled down with one reheat-
ing to 1 inch diameter. In each case the reheating was
done when the diameter had been reduced to $1\frac{1}{4}$ inch. The
temperature required for rolling was higher than for ordinary
aluminium-bronze, and the metal was noticeably harder.
The alloy which appeared to be hardest on rolling was No. 10
with about $7\frac{1}{2}$ per cent. of nickel and 5 per cent. of alu-
minium; next were Nos. 5 and 4 with 10 per cent. of
aluminium and $7\frac{1}{2}$ and 5 per cent. of nickel respectively.
One half piece of each of the hot rolled rods was then cold
rolled with four passes; another small piece was rolled hot
down to $\frac{1}{2}$ inch diameter and then cold rolled with three
passes. With the exception of the difference in hardness
already mentioned, all the alloys behaved similarly in rolling,
yielding perfectly sound rods.

Nos. 1 and 6, containing no nickel, were rolled hot down
to $\frac{15}{16}$ inch full diameter, and the cold working was carried
out on one half piece of each rod by drawing through a die
(cold drawing).

WIRE-DRAWING TESTS.

A portion of each rod was turned down to $\frac{3}{16}$ inch diameter for wire-drawing, which was carried out first on a small draw-bench, and afterwards by hand.

TABLE III.—*Wire-drawing Results.*

No.	Composition.			Finished at	
	Copper per Cent.	Nickel per Cent.	Aluminium per Cent.	Hole (1 to 50).	Corresponding Diameter in Inches.
1	89·94	...	10·06	44	0·047
2	89·14	1·04	9·82	48	0·040
3	87·66	2·46	9·88	40	0·058
4	85·11	4·95	9·94	15	0·123
5	82·82	7·48	9·70	8	0·153
6	94·98	...	5·02	50	0·033
7	93·96	0·94	5·10	50	0·033
8	92·68	2·38	4·94	50	0·033
9	89·84	4·84	5·32	50	0·033
10	87·48	7·31	5·21	50	0·033

All the wires were quite sound and smooth, and judged by their behaviour in the wire-drawing tests, the alloys of the two series stand in the following order :—

Aluminium, 10 *per Cent.*—Nos. 2, 1, 3. All these, however, broke even after repeated annealing before hole 50 was reached. Nos. 4 and 5 practically could not be drawn.

Aluminium, 5 *per Cent.*—Nos. 7, 8, 9, 10, 6. It will be noticed that all the members of this series could be drawn through the last hole (50), diameter 0·033 inch. The behaviour of the material containing nickel during these tests was found to be very much better than that of the pure 5 per cent. aluminium-bronze, thus showing that the presence of nickel improves the ductility of this alloy.

TENSILE TESTS.

In the tests about to be described, " H " refers to the cold rolled metal, " A " to the annealed and slowly cooled, " N "

to the air-cooled, and " Q " to the quenched material, while " C " indicates the chill castings. These latter were 1 inch in diameter and 10 inches long, and were made in pairs under the same conditions as the larger ingots already described. The annealing was carried out by heating the rods with a pyrometer attached, in a closed gas muffle, to 900° C., and keeping them at this temperature for fifteen minutes. The gas was then turned off, the damper closed, and the rods, after being allowed to cool slowly, were withdrawn when quite cold. The rate of cooling may be judged from the fact that the temperature fell to one-half in ninety minutes. Some preliminary experiments, in which the hardness of a number of annealed samples was measured by the scleroscope, showed that the annealing of the 10 per cent. aluminium alloys containing nickel was incomplete at 800° C. for fifteen minutes ; but after annealing at 900° C. for an equal time, no further change in the mechanical properties took place on extending the period of annealing to one hour.

The quenched specimens were rods 1 inch in diameter and 8 inches long, having a volume of 6·3 cubic inches, and weighing about 1·6 lb. ; they were heated up to 900° C., kept at that temperature for about fifteen minutes, and then quenched in cold water.

In view of the marked difference in properties between some of the quenched and the slowly-cooled specimens, it was thought desirable to make tests on air-cooled samples of the same dimensions as above, for which the rate of cooling was quicker than for the annealed series, though, of course, much slower than for the quenched metal.

The dimensions of the finished test-pieces were as follows :—

	Inches.
Diameter	0·564
Gauge length	2
Parallel	2¼

The tests were carried out on a Buckton universal horizontal testing machine fitted with a Wicksteed recorder. From the autographic stress-strain diagrams thus obtained the yield points were measured.

M

The results are given in Tables IV. to VIII., and some of them are shown graphically in Figs. 1 to 4.

The following is a summary of the effect of nickel on the mechanical properties of these alloys: any marked discontinuity in the mechanical properties was in nearly every case found to be associated with a change in the microstructure, and this will be referred to later when dealing with the micrographic analysis of the alloys.

Aluminium, 10 *per Cent.*

Chill Castings (Table IV. Fig. 1).—Increased maximum stress and yield point are obtained up to 10 per cent. of nickel at the expense of elongation and reduction of area. Above that point all the properties diminish. The 10 per cent. nickel alloy in the form of chill casting is improved by annealing at 900° C.

Annealed Rods (Table V. Fig. 2).—The mechanical properties are all considerably improved by the addition of 5 per cent. of nickel. Above this figure elongation and reduction of area begin to fall off.

Cold-rolled Rods (Table VI.).—The only marked change which takes place with increasing percentages of nickel is a considerable rise in the maximum stress, without any reduction in ductility. The mechanical treatment undergone by rod No. 1 was more drastic than in the case of the other members of the series.

Quenched Rods (Table VII.).—The effect of nickel in the quenched bars is to reduce slightly the maximum stress: the elongation and reduction of area increase with the percentage of nickel, but are very small throughout.

As the yield points of these quenched alloys were not well defined, Professor Bacon, at the request of the authors, very kindly undertook to make a careful determination of their elastic behaviour with the aid of an extensometer. The authors are indebted to Professor Bacon for the following report :—

"The elastic behaviour of alloys 1Q, 4Q, and 5Q was studied with the aid of a Ewing's extensometer applied to a gauge

TABLE IV.—*Tensile Tests. Chill Castings.*

No.	Composition.			Yield Point. Tons per Square Inch.	Maximum Stress. Tons per Square Inch.	Elongation per Cent. on 2 Inches.	Reduction of Area per Cent.	Remarks.
	Copper per Cent.	Nickel per Cent.	Aluminium per Cent.					
20 C	90·00	...	10·00	11·6	30·43	19·4	27·2	Fracture pale gold, silky. Surface slightly wavy.
21 C	89·48	0·96	9·56	12·8	35·50	20·2	21·5	Fracture pale gold, coarsely granular. Surface slightly wavy.
12 C	85·26	5·18	9·56	19·9	39·80	7·2	10·1	Fracture greyish, coarsely granular. Surface very slightly wavy.
13 C	79·94	10·14	9·92	25·1	38·48	2·8	4·6	Fracture grey, finely granular. Surface smooth.
22 C	75·34	14·62	10·04	16·5	29·18	3·2	5·5	Fracture grey, finely granular. Surface smooth.
19 CA	80·39	10·00	9·61	19·3	37·19	15·0	17·8	Annealed. Fracture grey, finely granular. Surface very slightly wavy.
23 C	94·88	...	5·12	5·0	18·73	68·0	58·2	Fracture pale gold, silky. Surface very wavy.
15 C	93·94	1·00	5·06	5·5	19·26	92·1	69·1	Fracture pale gold, silky. Surface very wavy.
16 C	90·04	5·05	4·91	5·6	18·67	86·5	73·4	Fracture very pale gold, silky. Surface wavy.
17 C	85·03	9·42	5·55	15·0	28·27	39·7	39·0	Fracture whitish grey, radially slightly crystalline. Surface wavy.
18 C	79·90	14·90	5·20	35·1	41·56	4·7	10·0	Fracture pinkish grey, radially crystalline. Surface smooth.
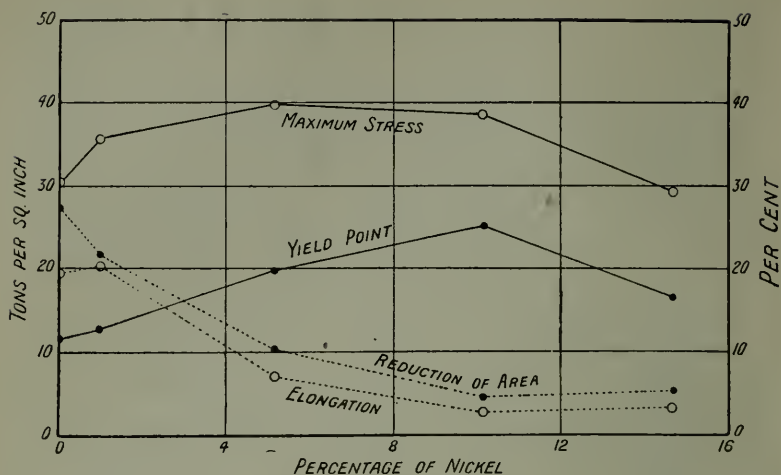
FIG. 1.—Tensile Tests.
Aluminium 10 per Cent.   Chill Castings.
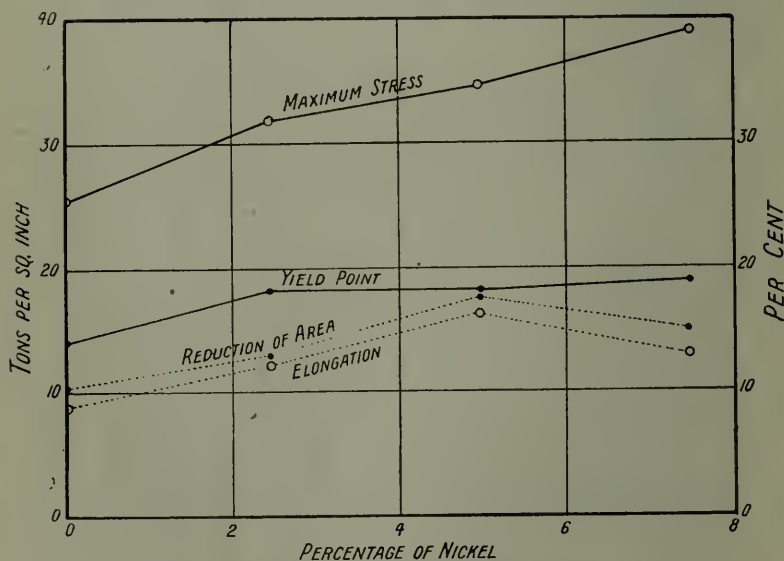
FIG. 2.—Tensile Tests.
Aluminium 10 per Cent.   Rolled and Annealed.

TABLE V.—*Tensile Tests. Annealed Rods.*

No.	Composition. Copper per Cent.	Nickel per Cent.	Aluminium per Cent.	Yield Point. Tons per Square Inch.	Maximum Stress. Tons per Square Inch.	Elongation per Cent. on 2 Inches.	Reduction of Area per Cent.	Remarks.
1 A	89·94	...	10·06	14·4	25·68	9·0	10·4	Fracture greyish, granular. Surface very slightly wavy.
3 A	87·66	2·46	9·88	18·1	31·88	12·3	13·0	Fracture greyish, granular. Surface very slightly wavy.
4 A	85·11	4·95	9·94	18·0	34·56	16·2	17·4	Fracture greyish, granular. Surface smooth.
5 A	82·82	7·48	9·70	18·8	38·91	13·1	15·1	Fracture light grey, slightly granular. Surface smooth. Broke in centre dot.
6 A	94·98	...	5·02	5·2	22·16	82·5	78·9	Fracture pale gold, silky. Surface wavy.
7 A	93·96	0·94	5·10	5·3	22·78	94·6	76·1	Fracture pale gold, silky. Surface wavy.
8 A	92·68	2·38	4·94	5·5	22·86	90·2	71·0	Fracture whitish grey, silky. Surface wavy.
9 A	89·84	4·84	5·32	9·4	25·58	70·0	60·2	Fracture whitish grey, less silky. Surface wavy.
10 A	87·48	7·31	5·21	24·0	39·00	25·6	26·8	Fracture pinkish grey, granular. Surface slightly frosted.
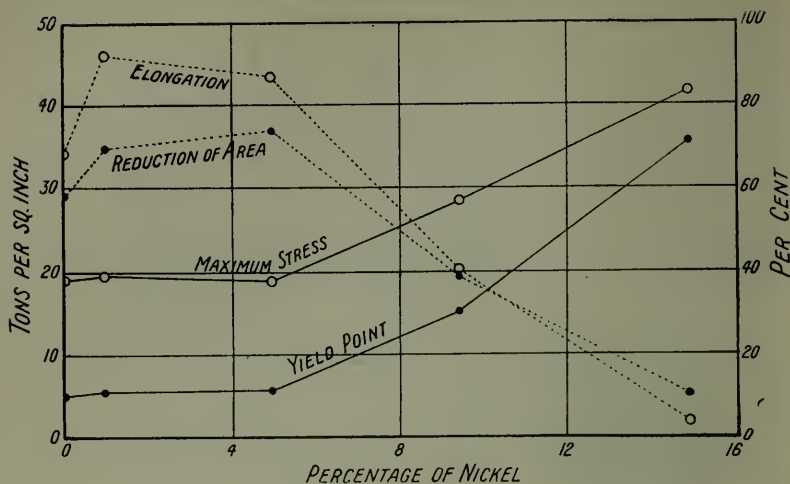
FIG. 3.—Tensile Tests.
Aluminium 5 per Cent. Chill Castings.
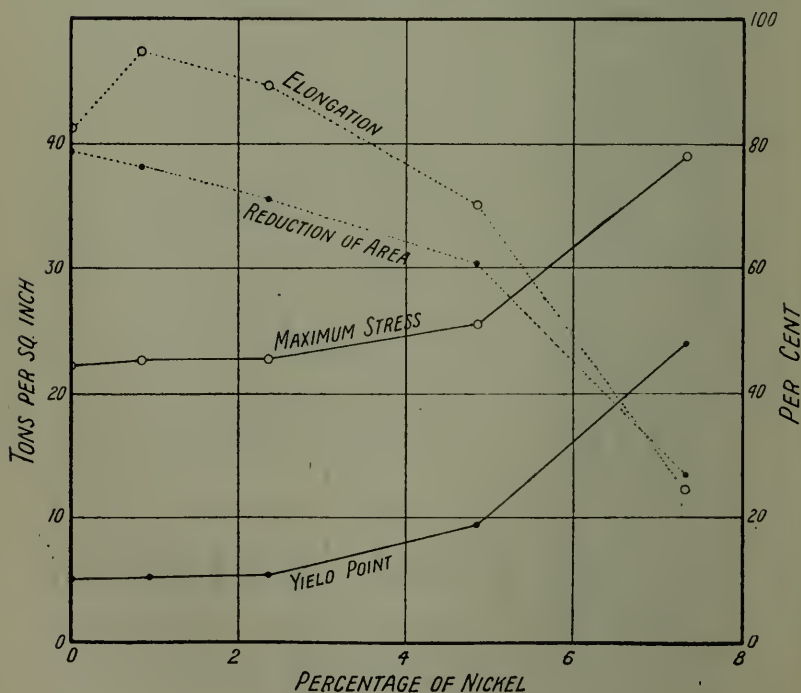
FIG. 4.—Tensile Tests.
Aluminium 5 per Cent. Rolled and Annealed.

TABLE VI.—*Tensile Tests. Cold-rolled Rods.*

No.	Composition			Yield Point. Tons per Square Inch.	Maximum Stress. Tons per Square Inch.	Elongation per Cent. on 2 Inches.	Reduction of Area per Cent.	Remarks.
	Copper per Cent.	Nickel per Cent.	Aluminium per Cent.					
1 H	89·94	...	10·06	42·0	44·28	9·0	12·4	Fracture greyish, granular. Surface slightly wavy.
3 H	87·66	2·46	9·88	36·9	51·24	13·0	11·0	Fracture greyish, finely granular. Surface smooth.
4 H	85·11	4·95	9·94	40·2	51·40	12·1	8·4	Fracture greyish, finely granular. Surface smooth.
5 H	82·82	7·48	9·70	47·8	52·01	12·3	16·3	Fracture greyish, finely granular. Surface smooth.
6 H	94·98	...	5·02	17·4	27·20	64·0	75·1	Fracture pale gold, silky, cup and cone. Surface frosted.
7 H	93·96	0·94	5·10	18·1	28·18	63·1	78·1	Fracture pale gold, silky, cup and cone. Surface frosted.
8 H	92·68	2·38	4·94	22·5	30·12	55·0	66·7	Fracture pale gold, silky, cup and cone. Surface frosted.
9 H	89·84	4·84	5·32	23·5	31·11	50·0	72·3	Fracture very pale gold, silky, cup and cone. Surface frosted.
10 H	87·48	7·31	5·21	31·1	36·30	28·8	41·0	Fracture silvery grey. Surface slightly wavy.

TABLE VII.—*Tensile Tests. Quenched Rods.*

No.	Composition.			Yield Point. Tons per Square Inch.	Maximum Stress. Tons per Square Inch.	Elongation per Cent. on 2 Inches.	Reduction of Area per Cent.	Remarks.
	Copper per Cent.	Nickel per Cent.	Aluminium per Cent.					
1 Q	89·94	…	10·06	35·0 *	53·55	2·3	3·9	Fracture pale gold, crystalline. Surface smooth.
3 Q	87·66	2·46	9·88	…	45·34	5·4	5·4	Fracture pale gold, crystalline. Surface smooth.
4 Q	85·11	4·95	9·94	18·0 *	46·56	4·2	5·5	Fracture very pale gold, crystalline. Surface smooth.
5 Q	82·82	7·48	9·70	20·0 *	49·58	6·3	5·5	Fracture grey, granular. Surface smooth.
6 Q	94·98	…	5·02	6·4	22·79	78·6	73·3	Fracture pale gold, silky. Surface wavy.
7 Q	93·96	0·94	5·10	6·6	22·83	85·6	73·8	Fracture pale gold, silky. Surface wavy.
8 Q	92·68	2·38	4·94	7·2	24·85	77·8	71·4	Fracture pale gold, silky. Surface frosted and wavy.
9 Q	89·84	4·84	5·32	7·6	24·22	86·8	72·4	Fracture whitish, silky. Surface wavy.
10 Q	87·48	7·31	5·21	11·4	29·77	52·1	65·1	Fracture silvery grey, granular. Surface frosted.

* Determined with an extensometer.

PLATE XI
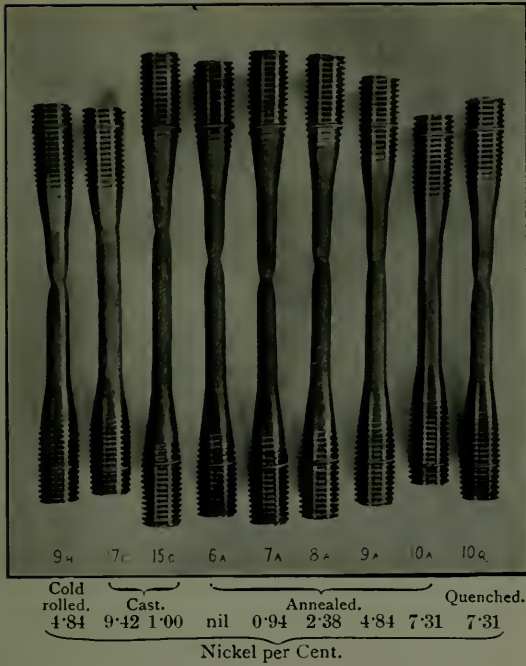
FIG. 5.—Aluminium 5 per Cent.
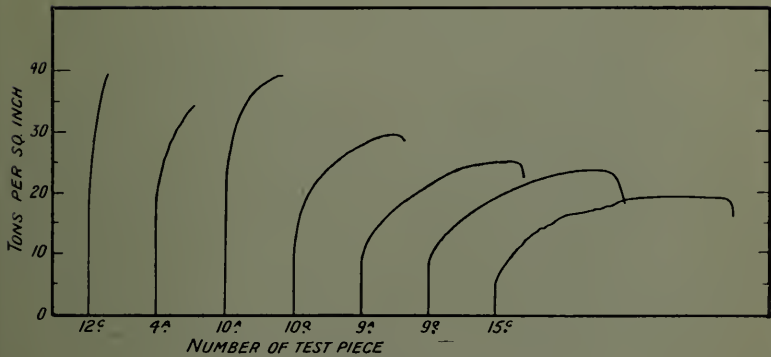
FIG. 6.—Stress-strain Diagrams.

PLATE XII

No. 1.

Copper . . . 82·82 ⎫
Nickel . . . 7·48 ⎬ per Cent.
Aluminium . . 9·70 ⎭
Cast. Magnified 100 diameters.

No. 2.
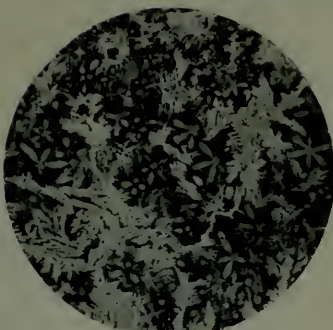
Copper . . . 79·94 ⎫
Nickel . . . 10·14 ⎬ per Cent.
Aluminium . . 9·92 ⎭
Cast. Magnified 100 diameters.

No. 3.
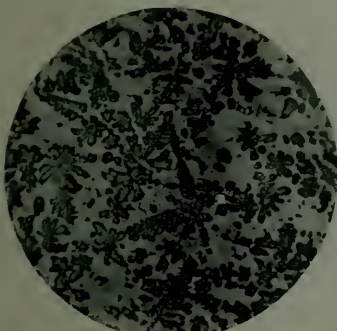
Copper . . . 74·26 ⎫
Nickel . . . 15·75 ⎬ per Cent.
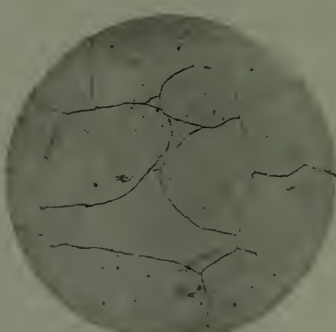Aluminium . . 9·99 ⎭
Cast. Magnified 100 diameters.

No. 4.
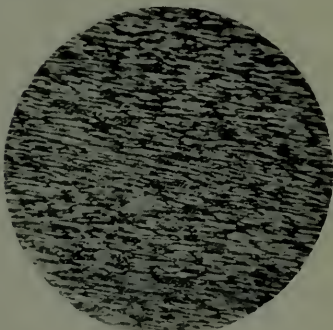
Copper . . . 82·82 ⎫
Nickel . . . 7·48 ⎬ per Cent.
Aluminium . . 9·70 ⎭
Cold Rolled. Magnified 100 diameters.

No. 5.
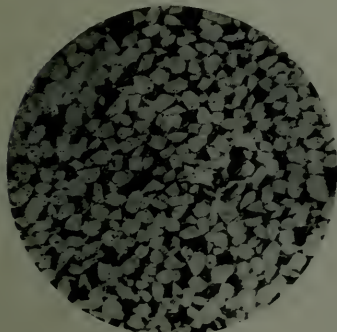
Copper . . . 85·11 ⎫
Nickel . . . 4·95 ⎬ per Cent.
Aluminium . . 9·94 ⎭
Rolled and Annealed.
Magnified 100 diameters.

No. 6.
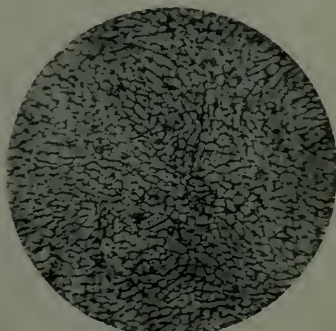
Copper . . . 82·82 ⎫
Nickel . . . 7·48 ⎬ per Cent.
Aluminium . . 9·70 ⎭
Rolled and Annealed.
Magnified 100 diameters.

PLATE XIII

No. 7.

Copper . . . 85·11 ⎫
Nickel . . . 4·95 ⎬ per Cent.
Aluminium . . 9·94 ⎭
Quenched. Magnified 25 diameters.

No. 8.
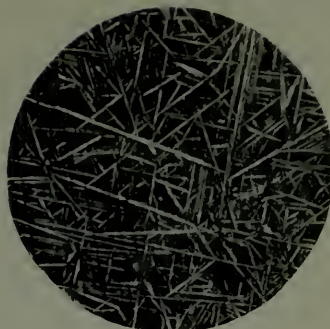
Copper . . . 85·11 ⎫
Nickel . . . 4·95 ⎬ per Cent.
Aluminium . . 9·94 ⎭
Quenched. Magnified 500 diameters.

No. 9.
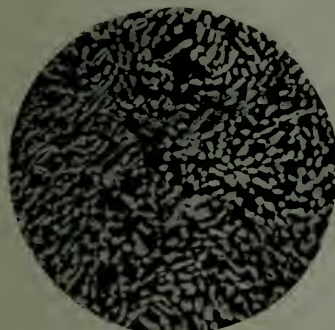
Copper . . . 82·82 ⎫
Nickel . . . 7·48 ⎬ per Cent.
Aluminium . . 9·70 ⎭
Quenched. Magnified 100 diameters.
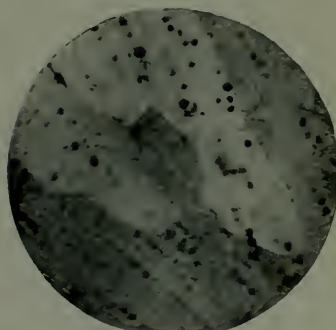
No. 10.

Copper . . . 93·94 ⎫
Nickel . . . 1·00 ⎬ per Cent.
Aluminium . . 5·06 ⎭
Cast. Magnified 100 diameters.
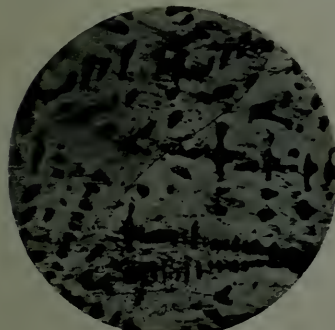
No. 11.

Copper . . . 87·48 ⎫
Nickel . . . 7·31 ⎬ per Cent.
Aluminium . . 5·21 ⎭
Cast. Magnified 100 diameters.
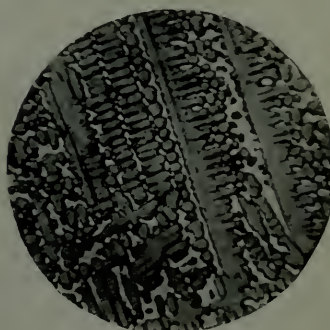
No. 12.

Copper . . . 79·90 ⎫
Nickel . . . 14·90 ⎬ per Cent.
Aluminium . . 5·20 ⎭
Cast. Magnified 100 diameters.

PLATE XIV
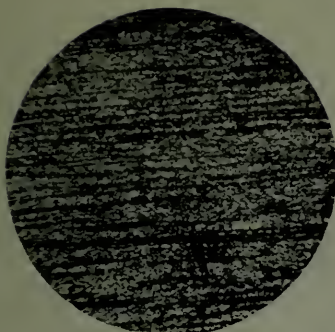
No. 13.

Copper . . . 87·48 ⎫
Nickel . . . 7·31 ⎬ per Cent.
Aluminium . . 5·21 ⎭
Cold Rolled.
Magnified 100 diameters.

No. 14.

Copper . . . 89·84 ⎫
Nickel . . . 4·84 ⎬ per Cent.
Aluminium . . 5·32 ⎭
Rolled and Annealed.
Magnified 100 diameters.
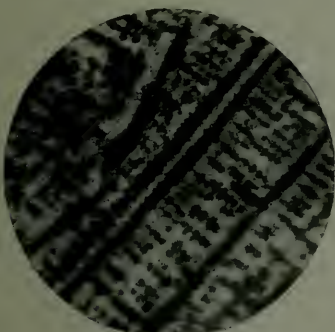
No. 15.

Copper . . . 87·48 ⎫
Nickel . . . 7·31 ⎬ per Cent.
Aluminium . . 5·21 ⎭
Rolled and Annealed.
Magnified 100 diameters.

No. 16.

The same specimen as No. 15; rather
deeply etched and re-polished.
Magnified 100 diameters.

No. 17.

Copper . . . 87·48 ⎫
Nickel . . . 7·31 ⎬ per Cent.
Aluminium . . 5·21 ⎭
Quenched. Magnified 100 diameters.

length of 2 inches, which made it possible to estimate exten-
sion to $\frac{1}{50,000}$ inch. The limit of proportionality of stress to
strain was reached in each case at a stress of approximately
8 tons per square inch. The increments of strain correspond-
ing to successive equal increments of stress then increased
continually, accompanied by a perceptible amount of permanent
set. In the case of 5Q a very decisive 'creeping point' was
reached at a stress of 20 tons per square inch. In the case
of 4Q a somewhat less marked creeping point was reached at
a stress of 18 tons per square inch. In the case of 1Q,
although the limit of proportionality was no higher than in
4Q or 5Q, that is, about 8 tons per square inch, no definite
evidence of creeping was detected until the stress reached an
intensity of 35 tons per square inch. The total amount of
creep which occurred at this load did not exceed $\frac{1}{10,000}$ inch,
and a self-hardening action then set in which enabled the
stress to be raised to 47 tons per square inch before pro-
nounced creeping was resumed."

On comparing the mechanical properties of the quenched
alloys with those of the annealed, it will be noticed that the
increase in maximum stress, due to quenching, is diminished
as the percentage of nickel rises. This fact, together with
the accompanying variations in elongation and reduction of
area, is shown in Table IX., in which the mechanical pro-
perties of the quenched and annealed bars are compared.

Air-cooled Rods (Table VIII.).—The mechanical properties
were intermediate between those of the quenched and annealed
series. The alloys thus treated resembled the latter series,
but possessed a higher maximum stress.

Aluminium, 5 per Cent.

Chill Castings (Table IV. Fig. 3).—Up to 5 per cent.,
nickel greatly improves the elongation and reduction of area
of these alloys without affecting the maximum stress and
yield point. With more than 5 per cent. of nickel, the latter
properties are rapidly improved, while the elongation and
reduction of area suffer a corresponding decrease. Neverthe-
less the yield point and maximum stress are both raised by

about four tons per square inch, before the ductility is reduced to that of the pure copper-aluminium alloy. The increase in elongation and reduction of area due to the first 1 per cent. of nickel is very marked, the chill casting showing an elongation of 92 per cent., compared with 68 per cent. for the corresponding copper-aluminium alloy without nickel.

Annealed Rods (Table V. Fig. 4).—Here again the effect of the first 1 per cent. of nickel on the ductility of the alloy is very marked. The maximum stress and yield point rise slowly until 5 per cent. of nickel is reached, and then very rapidly to $7\frac{1}{2}$ per cent. of nickel. The elongation and reduction of area begin to fall when the nickel exceeds 1 per cent., but they still retain a very high figure even in the 5 per cent. nickel alloy.

Cold-rolled Rods (Table VI.).—The maximum stress and yield point are raised while the elongation and reduction of area decrease slowly with between 1 and 5 per cent., and then more quickly with over 5 per cent. of nickel.

Quenched Rods (Table VII.).—The effect of nickel up to 5 per cent. on the quenched material is to increase slightly the yield point and maximum stress, and to improve the ductility. Above 5 per cent. the increase in yield point and maximum stress is more rapid, and there is a corresponding fall in elongation and reduction of area.

On comparing the results for the quenched rods with those for the annealed (see Table IX.), it will be noticed that with less than 5 per cent. of nickel, the maximum stress is hardly affected by quenching, though the yield point is slightly raised, and the elongation and reduction of area diminished. With 5 per cent. of nickel the ductility is greatly increased by quenching, while the maximum stress and yield point are both lowered. This effect is still more marked in the alloy with $7\frac{1}{2}$ per cent. of nickel, where the elongation and reduction of area are both more than doubled by quenching.

Air-cooled Rods (Table VIII.).—Unlike the members of the series with 10 per cent. of aluminium, the air-cooled 5 per cent. aluminium alloys, containing upwards of 5 per cent. of nickel, present mechanical characteristics which approximate to those of the quenched rather than the annealed metal.

No.	Composition. Copper per Cent.	Nickel per Cent.	Aluminium per Cent.	Yield Point. Tons per Sq. Inch.	Maximum Stress. Tons per Sq. Inch.	Elongation per Cent. on 2 Inches.	Reduction of Area per Cent.	Remarks.
4 N	85·11	4·95	9·94	18·1	41·76	12·9	10·0	Fracture greyish, finely granular. Surface smooth.
5 N	82·82	7·48	9·70	17·0	42·64	15·2	14·1	Fracture grey, finely granular. Surface smooth.
9 N	89·84	4·84	5·32	7·6	23·79	81·0	68·7	Fracture whitish grey. Surface wavy.
10 N	87·48	7·31	5·21	11·6	27·06	63·9	60·9	Fracture silvery grey. Surface frosted.

TABLE IX.—*The Effect of Quenching on the Mechanical Properties. A Comparison of Tables V. and VII.*

No.	Composition. Copper per Cent.	Nickel per Cent.	Aluminium per Cent.	Yield Point. Tons per Square Inch. Increase.	Decrease.	Maximum Stress. Tons per Square Inch. Increase.	Decrease.	Elongation per Cent. on 2 Inches. Increase.	Decrease.	Reduction of Area per Cent. Increase.	Decrease.
1	89·94	...	10·06	20·6*	...	27·87	...	...	7·7	...	6·5
3	87·66	2·46	9·88	...	...	13·46	...	...	6·9	...	7·6
4	85·11	4·95	9·94	0·0*	...	12·00	...	...	12·0	...	11·9
5	82·82	7·48	9·70	1·2*	...	10·67	...	...	6·8	...	9·6
6	94·98	...	5·02	1·2	...	0·63	...	...	3·9	...	5·6
7	93·96	0·94	5·10	1·3	...	0·05	...	...	9·0	...	2·3
8	92·68	2·38	4·94	1·7	...	1·99	...	...	12·4	0·4	...
9	89·84	4·84	5·32	...	1·8	...	1·36	16·8	...	12·2	...
10	87·48	7·31	5·21	...	12·6	...	9·23	26·5	...	38·3	...

* This increase is probably low in comparison with the other figures, as the yield points for the quenched rods were determined by means of an extensometer.

The maximum stress is even slightly lower than that of the quenched material, but this is probably to be accounted for by the absence of any hardening effect due to strains set up in quenching.

Fig. 5, Plate XI., shows the appearance and relative elongation of some of the alloys with 5 per cent. of aluminium broken in the tensile tests.

Reproductions of some of the stress-strain diagrams are given in Fig. 6, Plate XI. The first (starting from the left) is typical of the cast metal of the 10 per cent. aluminium series with a high percentage of nickel: the next is typical of all the rolled and annealed alloys with 10 per cent. of aluminium. The four following diagrams illustrate the effect of quenching on the alloys containing 5 per cent. of aluminium, with $7\frac{1}{2}$ and 5 per cent. of nickel respectively; while the last is typical of the cast metal of the 5 per cent. series, with nickel up to 5 per cent.

ALTERNATING STRESS TESTS.

The authors are indebted to Professor Arnold for carrying out these tests on specimens of the annealed, cold rolled, and quenched rods. The results obtained under standard conditions on the Arnold machine are given in Table X. and are shown graphically in Fig. 7.

The behaviour of the alloys under this test may be briefly stated as follows :—

Aluminium, 10 *per Cent.*—The resistance of the cold-rolled rods to alternating stress is reduced by the presence of nickel. The detrimental effect which is produced by annealing the 10 per cent. aluminium alloys, and which is so well exemplified by their behaviour in this test, is to some extent diminished by the presence of 5 per cent. of nickel, a conclusion also in accordance with the results of the tensile tests. The results for the quenched rods were very irregular and untrustworthy on account of their coarsely crystalline structure, and the tendency of the test-pieces to become " hinged " by the interlocking of the crystals.

Aluminium, 5 *per Cent.*—In each series an increasing percentage of nickel results in diminished resistance to alternating

TABLE X.—*Alternating Stress Tests.*

No.	Composition			Alternations endured under Standard Conditions.								
	Copper per Cent.	Nickel per Cent.	Aluminium per Cent.	Annealed.			Cold Rolled.			Quenched.		
				First Test.	Second Test.	Mean.	First Test.	Second Test.	Mean.	First Test.	Second Test.	Mean.
1	89·94	…	10·06	38	38	38	184	278	231			
3	87·66	2·46	9·88	80	34	57	160	170	165	Very irregular and untrustworthy.		
4	85·11	4·95	9·94	160	134	147	150	140	145			
5	82·82	7·48	9·70	32	76	54	64	44	54			
6	94·98	…	5·02	720	762	741	800	746	773	1030	1060	1045
7	93·96	0·94	5·10	760	732	746	602	558	580	860	864	862
8	92·68	2·38	4·94	742	600	671	330	378	354	700	776	738
9	89·84	4·84	5·32	454	436	445	254	204	229	408	392	400
10	87·48	7·31	5·21	208	178	193	152	148	150	282	234	258

stress; in the annealed state, however, there is no decrease until the nickel exceeds 1 per cent. The effect of quenching is to increase the resistance of these alloys to alternating stress.
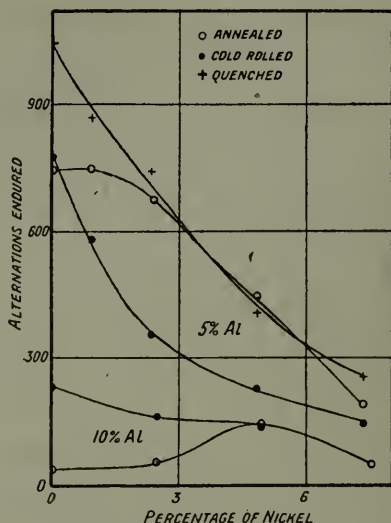
FIG. 7.—Alternating Tests.

HARDNESS TESTS.

The hardness of the alloys under different conditions of mechanical and heat treatment has been determined both by the Shore scleroscope (using the universal hammer) and by the Brinell method. The specimens tested were cylinders about 1 inch high and 1 inch in diameter, with polished surfaces. They were cut from the same rods as the tensile test-pieces, and had therefore received precisely the same thermal and mechanical treatment. The Brinell tests were carried out according to the standard conditions, using a 10-millimetre ball under a load of 3000 kilogrammes, the pressure being applied for one minute. The results given for the quenched series containing 5 per cent. of aluminium were, however, obtained with a load of 1000 kilogrammes.

The hardness numbers were calculated as follows :—

$$\frac{\text{Load in kilogrammes}}{\text{Spherical area of the concavity (in square millimetres)}}.$$

The hardness numbers obtained by both the scleroscope and Brinell methods are given in Table XI. Some of these results are shown in Figs. 8 and 9, where the Brinell numbers are represented by dots and a continuous line, and the scleroscope numbers by small circles and a dotted line. The relative hardness numbers recorded by both methods are in fairly close agreement, the lines through the two sets of readings running nearly parallel to one another ; but the effect of cold rolling, and especially of quenching, is greater in proportion on the scleroscope scale than in the Brinell hardness numbers.

It will be seen that the hardness curves in general have the same character as those representing yield point, the most noteworthy fact being the rapid increase in the hardness of the 5 per cent. aluminium alloys in the annealed state in the presence of upwards of 5 per cent. of nickel, and in the cast state when the nickel exceeds $7\frac{1}{2}$ per cent. This increase is so rapid that when the nickel reaches $7\frac{1}{2}$ per cent. the annealed metal with 5 per cent. of aluminium is harder than the corresponding alloy with 10 per cent. of aluminium ; and the same applies to the cast metal with 15 per cent. of nickel.

A comparison of the figures for the quenched material with those for the annealed may very conveniently be made by considering the hardening capacity of the alloys, *i.e.* the ratio of the hardness of the quenched material to that of the annealed. The values of this ratio given in Table XII. are calculated from the Brinell numbers ; the scleroscope numbers give similar series, but the numerical value of the ratio is somewhat larger.

It will be seen that as the percentage of nickel increases there is a very marked and (No. 4 alone excepted) regular diminution in the hardening capacity of the alloys with 10 per cent. of aluminium. In the 5 per cent. series the value of the ratio falls below 1 when the nickel reaches 5 per cent., and is still further reduced at $7\frac{1}{2}$ per cent. of nickel, indicating that these alloys are very considerably softened by

Table XI.—*Hardness Tests.*

No.	Composition			Hardness Numbers.							
				Scleroscope.				Brinell (Load of 3000 kilogrammes).			
	Copper per Cent.	Nickel per Cent.	Aluminium per Cent.	Chill Castings.	Annealed.	Quenched.	Cold Rolled.	Chill Castings.	Annealed.	Quenched.	Cold Rolled.
1	89·94	...	10·06	20·0	20·5	62·0	33·0	135	127	257	186
2	89·14	1·04	9·82	33·0	22·0	56·0	39·0	150	139	211	214
3	87·66	2·46	9·88	36·5	27·0	49·0	38·0	176	158	206	207
4	85·11	4·95	9·94	41·0	25·0	53·0	40·0	199	151	251	216
5	82·82	7·48	9·70	35·0	26·0	40·0	43·0	179	162	209	231
13*	79·94	10·14	9·92	35·0	28·0	45·0	...	182	173	214	...
14*	74·26	15·75	9·99	32·0	...	45·0	...	182	...	205	...
6	94·98	...	5·02	9·0	8·5	11·0	17·0	58	61+	52‡	114
7	93·96	0·94	5·10	10·5	10·5	11·0	18·5	59	64	56	113
8	92·68	2·38	4·94	11·0	11·0	11·5	21·0	59	66	62	124
9	89·84	4·84	5·32	12·0	12·5	12·0	23·0	60	80	61	136
10	87·48	7·31	5·21	13·5	27·0	17·0	27·5	77	167	92	156
17	85·03	9·42	5·55	17·0	...	...	...	115	...	...	...
18	79·90	14·90	5·20	37·0	...	...	...	173	...	...	...

* All the figures given for these alloys refer to the cast material.

+ With a load of 1000 kilogrammes Nos. 6, 7, 8, 9, and 10 gave hardness numbers 52, 56, 60, 78, and 152 respectively.

‡ The hardness numbers for the quenched rods of the 5 per cent. series were obtained with a load of 1000 kilogrammes.
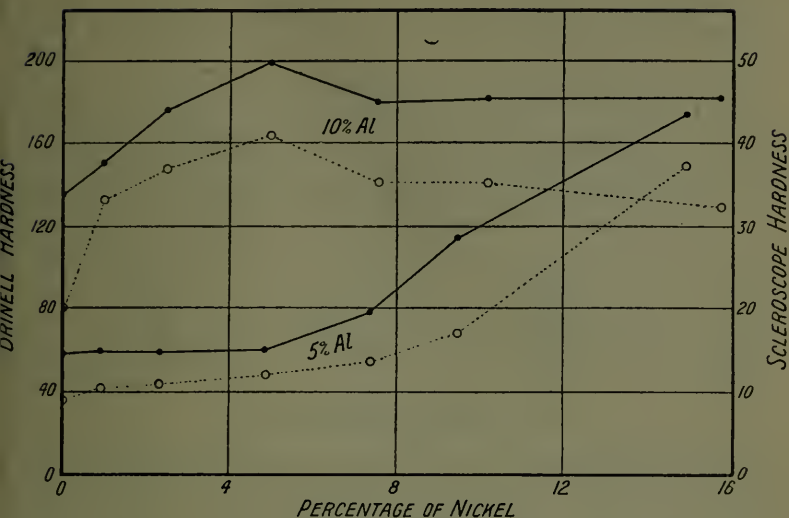
FIG. 8.—Hardness. Brinell and Scleroscope Tests on Chill Castings.
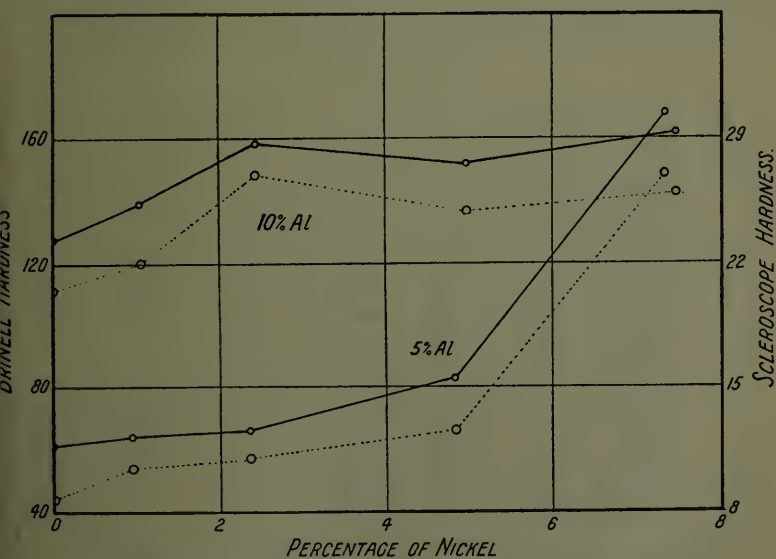
FIG. 9.—Hardness. Brinell and Scleroscope Tests on Annealed Rods.

quenching, a result entirely in accordance with the tensile
tests and microstructure.

TABLE XII.—*Effect of Quenching on the Hardness.*

No.	Aluminium 10 per Cent. (Load 3000 Kilogrammes.) Ratio $\frac{\text{Hardness of Quenched Alloy}}{\text{Hardness of Annealed Alloy}}$	No.	Aluminium 5 per Cent. (Load 1000 Kilogrammes.) Ratio $\frac{\text{Hardness of Quenched Alloy}}{\text{Hardness of Annealed Alloy}}$
1	2·02	6	1·00
2	1·51	7	1·00
3	1·30	8	1·03
4	1·66	9	0·78
5	1·29	10	0·60
13 *	1·21		

For chemical composition see Table XI.

SPECIFIC GRAVITIES.

The specific gravities of the alloys as chill castings, and also
as annealed, cold rolled, and quenched rods, are given in Table
XIII. In spite of the fact that the density of nickel (8·80) †

TABLE XIII.—*Specific Gravity (expressed as Grammes per Cubic Centimetre).*

No.	Composition.			Specific Gravity.			
	Copper per Cent.	Nickel per Cent.	Aluminium per Cent.	Chill Castings.	Annealed.	Quenched.	Cold Rolled.
1	89·94	...	10·06	7·54	7·54	7·54	...
3	87·66	2·46	9·88	7·55	7·54	7·54	7·56
4	85·11	4·95	9·94	7·56	7·63	7·63	7·63
5	82·82	7·48	9·70	7·60	7·57	7·58	7·57
13	79·94	10·14	9·92	7·53	...	...	...
14	74·26	15·75	9·99	7·60	...	...	...
6	94·98	...	5·02	...	8·18	8·18	8·17
8	92·68	2·38	4·94	8·14	8·17	8·16	8·16
9	89·84	4·84	5·32	8·15	8·18	8·18	8·17
10	87·48	7·31	5·21	8·15	8·19	8·18	8·18
17	85·03	9·42	5·55	8·13	...	...	...
18	79·90	14·90	5·20	8·14	...	...	...

* The figures for No. 13 refer to the quenched and annealed cast material.
† Roberts-Austen, "Introduction to Metallurgy," 1910, p. 67.

is less than that of copper (8·93),* it will be seen that the presence of nickel brings about a distinct increase in the specific gravity, this being most marked in the 10 per cent. aluminium alloy with 5 per cent. of nickel. In this series, with larger amounts of nickel, the specific gravity falls in spite of a slight decrease in aluminium. This fact, as well as the differences between the cast and annealed alloys of the same series, is probably significant in connection with the constitution of these alloys.

The results given in Table XIII. were obtained with specimens cut from the same rods as the test-pieces which had received the thermal and mechanical treatment already described.

MELTING-POINTS.

The melting-points of a number of the alloys were determined with a thermo-electric couple and a direct reading millivoltmeter. The results which are tabulated in Table XIV. show that the addition of nickel to the 5 per cent. aluminium-copper alloy results in an immediate and considerable rise in melting-point; while with the 10 per cent. alloy there appears to be a slight fall at first followed by a rise before the nickel reaches 5 per cent.

TABLE XIV.—*Melting-points.*

No.	Composition.			Melting-point, Degrees C.
	Copper per Cent.	Nickel per Cent.	Aluminium per Cent.	
20	90·00	...	10·00	1042
3	87·66	2·46	9·88	1039
12	85·26	5·18	9·56	1042
5	82·82	7·48	9·70	1053
13	79·94	10·14	9·92	1079
22	75·34	14·62	10·04	1063
6	94·98	...	5·02	1054
8	92·68	2·38	4·94	1081
16	90·04	5·05	4·91	1093
10	87·48	7·31	5·21	1097
17	85·03	9·42	5·55	1108
18	79·90	14·90	5·20	1119

* Roberts-Austen, "Introduction to Metallurgy," 1910, p. 67.

Conductivity for Electricity.

The resistance of definite lengths of the wires, made as described under " wire drawing " and subsequently annealed

Table XV.—*Electrical Conductivities at* 13° *C.* ± 2°.

| No. | Composition. | | | Specific Resistance (Ohms × 10⁻⁶). | Conductivity (Copper=100). |
	Copper per Cent.	Nickel per Cent.	Aluminium per Cent.		
1	89·94	...	10·06	10·27	16·0
2	89·14	1·04	9·82	11·74	14·0
3	87·66	2·46	9·88	14·40	11·4
6	94·98	...	5·02	9·85	16·7
7	93·96	0·94	5·10	10·88	15·1
8	92·68	2·38	4·94	12·56	13·1
9	89·84	4·84	5·32	15·47	10·6
10	87·48	7·31	5·21	18·45	8·9

by heating to redness and cooling in air, was measured by the Wheatstone bridge method with the aid of a carefully stand-

Fig. 10.—Relative Conductivity for Electricity (Copper=100).

ardized resistance box. The results are given in Table XV., which shows the specific resistances of the alloys in microhms (ohms × 10⁻⁶), and also the percentage conductivity of each member of the series relative to that of pure copper * at the same temperature. These values are also shown graphically in Fig. 10.

It will be noticed that the conductivity of the 5 per cent. alloy is only very slightly greater than that of the alloy containing 10 per cent. of aluminium. The effect of nickel in both cases is to diminish the conductivity.

* Swan and Rhodin, *Proceedings of the Royal Society*, 1894, vol. lvi. p. 81.

In view of the changes produced in alloys Nos. 9 and 10 by quenching, determinations of the conductivity were also made on slowly cooled samples and on samples quenched from 900° C. in cold water. These are given in Table XVI.

TABLE XVI.—*Effect of Quenching on the Conductivity.*

No.	Composition.			Specific Resistance (Ohms × 10⁻⁶).			Conductivity (Copper=100).		
	Copper per Cent.	Nickel per Cent.	Aluminium per Cent.	Annealed. Slowly Cooled.	Air-cooled.	Quenched.	Annealed. Slowly Cooled.	Air-cooled.	Quenched.
9	89·84	4·84	5·32	15·49	15·47	15·54	10·6	10·6	10·6
10	87·48	7·31	5·21	18·01	18·45	18·43	9·15	8·93	8·94

For No. 9 all three methods of treatment give wire of the same specific resistance within the limits of experimental error, but the resistance of the alloy with $7\frac{1}{2}$ per cent. of nickel is lowered by annealing and slow cooling; while the quenched material has approximately the same resistance as the air-cooled.

CORROSION TESTS.

Plates of metal having the dimensions $2·0 \times 0·75 \times 0·1$ inch were tested both in the cold rolled and annealed conditions. The annealed plates had been heated in a muffle to a good red heat, and cooled in air. The arrangement used for these experiments was the same as that previously described by one of the authors.* Each plate, after being polished and thoroughly cleaned, was weighed and suspended from a glass hook attached to a piece of wood which rested on the edges of a porcelain tank. At the end of the tests the plates were carefully cleaned, dried, and weighed. For purposes of comparison plates of Muntz metal (copper 61 per cent.), and of naval brass (70 : 29 : 1) were included.

Fresh Water Tests.—A gentle stream of tap water was kept flowing continuously through the tank for 144 days, during

* *Journal of the Institute of Metals*, No. 2, 1913, vol. x. p. 360.

which time the plates were taken out and gently rubbed once a fortnight. The chemical composition, as given below, shows the tap water to be " soft " and of high quality :—

Constituent.						Grains Per Gallon.
Free ammonia	.	.	.	.	.	0·0007
Albuminoid ammonia	.	.	.	.	.	0·0035
Silica	.	.	.	.	.	0·035
Ferric oxide	.	.	.	.	.	0·07
Sodium chloride	.	.	.	.	.	0·68
Magnesium chloride	.	.	.	.	.	0·25
Magnesium carbonate	.	.	.	.	.	0·36
Calcium sulphate	.	.	.	.	.	0·58
Calcium carbonate	.	.	.	.	.	2·15

The results are given in Table XVII., where it will be seen that if the nickel has any action it is to increase the rate of corrosion. This increase is clearly shown in the series containing 5 per cent. of aluminium, but in the other series the loss in weight due to corrosion does not vary so regularly. In all cases, however, the action of this very pure tap water on the alloys was exceedingly small. The plates were only slightly tarnished, and were all perfectly smooth. The alloys containing 1 per cent. of aluminium showed dark spots in places, the Muntz metal was more tarnished and darker in colour than any of the 10 per cent. aluminium alloys, and the naval brass was covered with brownish-red patches where dezincification had begun to take place.

Sea Water Tests.—The sea water which was obtained from a bay in the Bristol Channel was changed every fortnight, and at the same time the plates were taken out and gently rubbed. The duration of the trials was 123 days. The results are recorded in Table XVII., and those for the annealed plates shown graphically in Fig. 11.

The figures given for Muntz metal, naval brass, the copper-aluminium alloys with 10 per cent. and 1 per cent. of aluminium, all agree with those found by Messrs. Vivian & Sons,[*] and by Carpenter and Edwards. The effect of nickel up to 10 per cent. is in all cases greatly to reduce the corrosion of the alloys by the sea water, the effect of the first 1 per cent. of nickel on the 10 per cent. alloy being very marked. There was no appreciable difference in the behaviour of the annealed

[*] *Proceedings of the Institution of Mechanical Engineers*, Part 1, 1907, p. 365.

TABLE XVII.—*Corrosion Tests.*

| No. | Composition | | | Loss in Weight in lbs. per Square Foot per Month. | | | |
| | Copper per Cent. | Nickel per Cent. | Aluminium per Cent. | Sea Water. | | Fresh Water. | |
				Annealed.	Cold Rolled.	Annealed.	Cold Rolled.
1	89·94	...	10·06	0·00091	0·00059	0·00009	0·00008
a	89·55	0·97	9·48	0·00022	0·00024	0·00006	0·00009
b	85·15	4·94	9·91	0·00012	0·00013	0·00011	0·00012
c	80·13	9·98	9·81	0·00009	0·00001	0·00009	0·00008
6	94·98	...	5·02	0·00031	0·00034	0·00006	0·00006
e	94·04	0·92	5·04	0·00031	0·00031	0·00008	0·00008
f	90·09	4·90	5·01	0·00012	0·00012	0·00007	0·00009
g	85·08	10·07	4·85	0·00005	0·00002	0·00012	0·00012
24	98·96	...	1·04	0·00244	0·00211	0·00011	0·00010
i	97·75	1·03	1·22	0·00221	0·00214	0·00010	0·00013
j	95·21	3·57	1·22	0·00106	0·00163	0·00015	0·00012
k	89·24	9·83	0·93	0·00018	0·00015	0·00011	0·00010
Muntz metal	Copper 61 per cent. ; Zinc 39 per cent.			0·00158	0·00143	0·00040	0·00033
Naval brass	Copper 70 per cent. ; Zinc 29 per cent. ; Tin 1 per cent.			0·00140	0·00131	0·00020	0·00022

and cold rolled metal. The plates after their immersion in sea water were generally smooth, but varied in appearance. The pure 10 per cent. copper-aluminium alloy was much darker in colour, and the surface was roughened, while those containing nickel were quite smooth and only slightly dimmed, but had assumed a greenish tinge. The 5 per cent. aluminium alloy showed a dull reddish-yellow colour, with 1 per cent. of
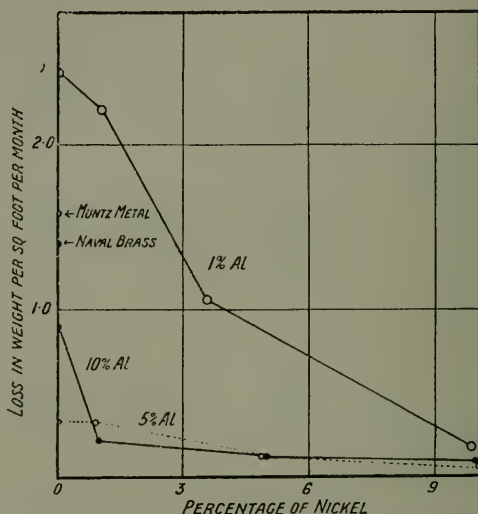
FIG. 11.—Corrosion Tests. Loss in Weight in $\frac{1}{1000}$ths of a Pound. Annealed Plates in Sea Water.

nickel this was lighter; while the alloys with 5 and 10 per cent. of nickel respectively remained perfectly bright. The 1 per cent. aluminium alloys with low nickel were coated with a fine dark red deposit, but when the nickel reached 10 per cent. the surface assumed a dull greenish colour. Meanwhile the surface of the Muntz metal had become dimmed and covered with small reddish excrescences: and the Naval brass showed a greenish deposit easily removed, leaving a reddish surface underneath.

MICROSCOPIC FEATURES OF THE ALLOYS.

All the alloys have been examined microscopically, the specimens being etched as a rule with an acid solution of ferric

chloride containing four parts of a solution of ferric chloride in water (1 : 12), and one part of concentrated hydrochloric acid.

It was necessary, however, in dealing with some of the alloys containing 5 per cent. of aluminium to dilute this to one-quarter strength by the addition of three parts of water, while ammonium persulphate was also found useful in some cases. All the accompanying photomicrographs were taken by direct illumination.

Aluminium, 10 *per Cent.*

Cast Structures.—The structure of the alloys containing less than 5 per cent. of nickel consists solely of the α and β constituents, exactly resembling those of the 10 per cent. aluminium-copper alloy. At 5 per cent. of nickel a few blue veins are visible in the α constituent at a magnification of 350 diameters. At $7\frac{1}{2}$ per cent. of nickel these are more noticeable (Plate XII., Micrograph No. 1), and penetrate into the β constituent. At the same time the size of the crystals is reduced, and the alloy with 10 per cent. of nickel shows a finer $\alpha + \beta$ structure with a much smaller proportion of the β constituent, while there are also present crystallites of the blue constituent (Micrograph No. 2). When 15 per cent. of nickel is reached the β constituent is entirely replaced by the greyish blue substance embedded in a ground mass of the α solution (Micrograph No. 3).

Cold-rolled Structures.—The longitudinal sections of all the cold-rolled rods showed the characteristic rolling structure, the blue constituent being first visible at $7\frac{1}{2}$ per cent. of nickel (Micrograph No. 4).

Annealed Structures.—Up to $2\frac{1}{2}$ per cent. of nickel the alloys show the ordinary $\alpha + \beta$ structure. At 5 per cent. of nickel (Micrograph No. 5) the crystals are smaller, and a little of the blue constituent may be seen in half tone. At $7\frac{1}{2}$ per cent. of nickel an entire change has taken place in the structure. The specimen appeared to be softer in polishing : the structure (shown in Micrograph No. 6), though similar in appearance to the $\alpha + \beta$ structure, showed no trace whatever of the β constituent at high magnification, but consists solely of fine blue lines in the α constituent. Similarly the cast metal con-

taining 10 per cent. of nickel, after annealing and slow cooling, no longer showed any β, but simply α + blue constituent. In consequence of the high actinic effect of this blue substance, it is difficult to obtain photographically a good contrast with the golden α solution, but under the microscope its colour renders it easily distinguishable to the eye, even in fine lines.

Quenched Structures.—The alloys low in nickel showed the characteristic acicular structure of the quenched copper-aluminium alloys, but as the nickel increases up to 5 per cent. the needles become finer. The appearance of the alloy with 5 per cent. of nickel is shown in Plate XIII., Micrographs Nos. 7 and 8. The former shows the structure at a magnification of 25 diameters, but the interior of the large crystals there shown presents a fine acicular structure at a magnification of 500 diameters. On passing to $7\frac{1}{2}$ per cent. of nickel (Micrograph No. 9), the structure is no longer acicular, but presents an appearance similar to that of the ordinary annealed copper-aluminium alloy, the dark constituent being β with only a mere trace of the blue substance. On quenching the cast alloy containing 10 per cent. of nickel in a similar manner, the β constituent which was absent after slow cooling was restored, though a considerable amount of the blue constituent remained unaffected by the change.

Aluminium, 5 per Cent.

Cast Structures.—The alloys with 5 per cent. of nickel and under consist of large α crystals which exhibit coring. Micrograph No. 10, showing the 1 per cent. alloy, is typical of these ; the coring becomes more marked as the percentage of nickel increases, but disappears on annealing. The alloy with $7\frac{1}{2}$ per cent. of nickel (Micrograph No. 11) shows very heavy coring (or probably two constituents) which did not disappear, but was modified by annealing. The second constituent is certainly present in the 10 per cent. nickel alloy, and this at first etches brown, but at 15 per cent. (Micrograph No. 12) the alloy consists of long, blue dendritic crystals set in a ground mass of golden α constituent.

Cold-rolled Structures.—As the nickel increases the longitudinal sections show a gradual change from fairly coarse

broken crystals of α with only slight rolling structure to the fine crystals and marked rolling structure of Micrograph No. 13, Plate XIV., with $7\frac{1}{2}$ per cent. of nickel.

Annealed Structures.—Up to 5 per cent. of nickel the micro-sections show the α constituent only with plentiful twinning (Micrograph No. 14). In places at 5 per cent., and more noticeably at $7\frac{1}{2}$ per cent. of nickel (Micrograph No. 15), dark areas not unlike dendritic crystals varying in colour from brown to blue according to the depth of etching, are found in the slowly cooled metal, cutting right across the clearly defined crystals of α. The presence of the crystal boundaries of the α constituent is best revealed by rather deep etching and subsequent repolishing. Micrograph No. 16 represents the same specimen as No. 15, treated in this manner.

Quenched Structures.—Up to 10 per cent. of nickel the alloys are all softer to polish after quenching, and consist of the α constituent only, with plentiful twinning, but with no other constituent. Micrograph No. 17 again shows the $7\frac{1}{2}$ per cent. nickel alloy, but the bluish-brown constituent produced on slow cooling has been suppressed, and it does not appear with 10 per cent. of nickel. At 15 per cent. of nickel the structure is similar to the annealed, showing that no change is brought about by quenching.

Of the typical α and β constituents of the copper-aluminium alloys the α certainly, and possibly the β, will dissolve nickel without change in appearance; but in addition to these, two other constituents have been met with in the alloys examined, viz. :—

A. In the 10 per cent. aluminium series : a greyish-blue constituent which appears in the slowly cooled metal at 5 per cent. of nickel, but is suppressed by quenching up to $7\frac{1}{2}$ per cent. of nickel. With 10 per cent. and more it forms primary crystals which are not removed by quenching.

B. In the 5 per cent. aluminium series : a constituent which in the slowly cooled metal first appears at 5 per cent. of nickel, but which is suppressed by quenching from $900°$ C., until the nickel exceeds 10 per cent. As a secondary constituent this etches brown or bluish, but with 15 per cent. nickel, what is probably the same constituent forms primary

dendritic crystals of a clear blue colour which persists after quenching.

Until the constitution of the copper-nickel-aluminium alloys has been more systematically studied, it is not possible to identify these constituents with certainty; but since they in no way resemble any phase of the copper-aluminium alloys, it may be remarked that there remain the following possibilities :—

(1) A nickel-aluminium compound.
(2) A copper-nickel solid solution (probably containing aluminium).
(3) A ternary compound.

The authors have reason to believe that the two constituents are not the same, and incline to the opinion that the substances A and B correspond respectively to the first and second alternatives mentioned above.

However, while the exact nature of these constituents is uncertain, their effect on the mechanical properties of these alloys is well defined. In the cast series the appearance of the constituent A, or possibly the simultaneous disappearance of β, diminishes the hardness and lowers all the mechanical properties. In the annealed rods the alloy with 5 per cent. of nickel, that is, about the limit of the $\alpha + \beta$ structure when nearly all the nickel is in solution, shows maximum elongation, reduction of area, resistance to alternating stress, and specific gravity, and the replacement of β by the blue substance lowers all these properties.

In the series with 5 per cent. of aluminium, the constituent B confers great hardness on the 15 per cent. nickel alloy : the increase in hardness in the cast and annealed metals begins at $7\frac{1}{2}$ and 5 per cent. of nickel respectively, where this substance begins to separate. The most notable example of its effect was found in the alloy with $7\frac{1}{2}$ per cent. of nickel, where its separation on slow cooling results in greater hardness, higher yield point, and maximum stress, with reduced elongation, and reduction of area.

It will be seen from Table XVIII. that a wide range of properties may be obtained by suitable mechanical and heat treatment of this alloy.

TABLE XVIII.

No. 10. Nickel 7½%. Aluminium 5%.	Yield Point. Tons per Sq. Inch.	Maximum Stress. Tons per Sq. Inch.	Elonga-tion per Cent. on 2 Inches.	Reduction of Area per Cent.	Brinell Hardness.	Alterna-tions Endured.
Air-cooled . . .	11·6	27·06	63·9	69·9	...	...
Quenched . . .	11·4	29·77	52·1	65·1	92	258
Annealed . . .	24·0	39·00	25·6	26·8	167	193
Cold rolled . .	31·1	36·30	28·8	41·0	156	150

Slow cooling also increases the conductivity and the specific gravity. Determinations of the latter property on the same sample before and after quenching led to the following results :—

Aluminium, 5 per Cent.

	Annealed.	Quenched.	Decrease in Volume on Slow Cooling.
5 per cent. Nickel	8·178	8·176	0·2 parts per 1000
7½ ,, ,,	8·192	8·180	1·5 ,, ,, ,,

The latter figures, which are the mean of two determinations, may be taken to indicate that the change on slow cooling is accompanied by a considerable decrease in volume ; and since the properties of the air-cooled rods of this alloy were approximately those of the quenched, it would appear that the separation of the constituent B from the homogeneous solid solution takes place very slowly.

APPENDIX.*

Effect of Acids and Alkalis on the Nickel-Aluminium-Copper Alloys.

In view of the very low rate of corrosion of the nickel-aluminium-copper alloys in sea water, a number of experiments were made to determine the effect of acid and alkaline liquors on these alloys. Small cylinders of the metals, $\frac{3}{8}$ inch diameter by 2 inches long, were immersed in vinegar, deci-normal solutions of sulphuric acid, hydrochloric acid, and sodium hydroxide respectively, for about five weeks, the rods being rubbed at intervals of about a week and the liquid renewed. The figures given in the accompanying table indicate the behaviour of the alloys under these conditions.

In $\frac{N}{10}$ *NaOH.*—The rate of corrosion is very small and is diminished by the presence of nickel, though not so greatly as in sea water. The surfaces of all the specimens were dull after immersion.

In Vinegar.—The presence of nickel greatly increases corrosion, especially in the 10 per cent. aluminium series. The pure 10 per cent. aluminium alloy remained bright: all the rest were dull.

In $\frac{N}{10}$ *H_2SO_4.*—In this case also the rate of corrosion is greatly increased by nickel in the 10 per cent. aluminium series, but is almost unaffected in the alloys with 5 per cent. aluminium. The surfaces of numbers 1 and 5 were bright: the others were dull.

In $\frac{N}{10}$ *HCl.*—The corrosion in every case is very great, the pure 10 per cent. aluminium-copper alloy withstanding the action of the acid best. The rate of corrosion of the 5 per cent. aluminium alloy is unaffected by the presence of nickel; but that of the alloy with 10 per cent. aluminium is very greatly increased as the nickel rises. The pure 10 per cent. aluminium alloy alone remained bright: all the others were

* Contributed since the paper was read.—Ed.

thickly coated with a dark deposit, and showed a green colour after cleaning and drying.

These results seem to indicate that the alloys containing nickel resist corrosion by sea water and by alkaline solutions better than the pure aluminium-copper alloys, while the latter withstand the action of acids better than those containing nickel.

Corrosion Texts.   Effect of Acids and Alkalis.

No.	Copper per Cent.	Nickel per Cent.	Aluminium per Cent.	Loss of Weight in lbs. per Square Foot per Month.			
				$\frac{N}{10}$ NaOH.	Vinegar.	$\frac{N}{10}$ H_2SO_4.	$\frac{N}{10}$ HCl.
1	89·94	...	10·06	0·00022	0·0004	0·0015	0·0016
4	85·11	4·95	9·94	0·00018	0·0090	0·0036	0·0406
5	82·82	7·48	9·70	0·00019	0·0089	0·0142	0·0374
6	94·98	...	5·02	0·00042	0·0075	0·0060	0·039
9	89·84	4·84	5·32	0·00026	0·0060	0·0062	0·035
10	87·48	7·31	5·21	0·00023	0·0104	0·0058	0·036

DISCUSSION.

Dr. WALTER ROSENHAIN, F.R.S. (Member of Council), said that the paper itself was extremely interesting to him personally, because he had worked on another ternary system of aluminium-copper. In passing, he suggested to the authors it would be desirable, in conformity with the findings of the Nomenclature Committee's Report, to speak of the alloys mentioned as " nickel-aluminium-copper."

One statement in the paper was remarkable, namely, that the corrosion of aluminium-copper alloys by sea water was greatly reduced by the presence of nickel. Corrosion by sea water of the aluminium-coppers was extremely small indeed to begin with in the case of the 10 per cent. alloy, and if it was " greatly reduced " the alloy ought to gain in weight ! He would like to know whether the authors could give information as to the effect of the nickel on the casting and machining properties of the alloys. One could see that there were great possibilities in those alloys from a great many practical points of view, where special properties were required, but one of the great difficulties in inducing people to avail themselves of those special properties, even in the case of the aluminium-coppers, was their very large shrinkage in the mould ; they required a great deal of feeding, and it was extremely difficult to prevent the castings from drawing. It *could* be prevented ; he frequently made castings in the laboratory of all sorts of shapes and forms, and perfectly sound castings could be obtained if only the method was known and the necessary trouble and waste of material were expended. It would be very interesting to know how nickel affected that matter—whether it made it better or worse, and also with regard to machining. The 10 per cent. aluminium-copper was not easy to machine, and he would be glad to know whether the addition of nickel made it easier or harder.

With regard to the paper itself, there were only two points on which he desired to offer a little comment. In the first place, apparently tensile tests had been taken by means of the autographic stress-strain recorder, and the yield points had been read from it, which was a vague thing in any case. He considered it ought to have been done by some more precise means than that. In his opinion the autographic stress-strain recorder was admittedly an imperfect and unsatisfactory appliance. A very beautiful contrivance had recently been designed by Professor Dalby, and when it was available it would be found that it would be the best way of carrying out tests. One would like to have seen the yield points taken by a rather more accurate method.

In the second place, he was sorry to see that the authors, who had carried out such an important research, had confined their dynamic tests to Arnold's so-called alternating stress test. That test might have a value or it might not ; his own opinion was that it had very little value. It was one test of a very peculiar kind, and a test which bore little or no relation to other standard or well-recognized dynamic tests. He would like to have seen a single blow impact test or a repeated bending impact test or something of that kind, or an alternating stress test, which would

have given far greater insight into the dynamic properties of the alloys than could possibly be obtained by the test which the authors had chosen. He had nothing to say against the inclusion of that test; he had included it in his own papers repeatedly; but the fact of taking it by itself meant to his mind that the results would have to be accepted with very considerable caution.

Beyond that he would only say the Institute was to be congratulated on having such a paper presented to it.

Professor A. K. HUNTINGTON, Assoc.R.S.M. (Past-President), said that as he had happened to have carried out some work at different times on the alloy mentioned, he might call attention to one or two points in connection with it. It seemed to him that one of the difficulties in working with the aluminium-copper alloys was to get them made up thoroughly satisfactorily. He had compared some of the aluminium-copper results given in the paper with those obtained by Professor Carpenter, and he had found that Professor Carpenter obtained better mechanical tests for the aluminium-copper than those given in the paper. That pointed to a difference in the making up of the alloy in some way or another. About ten years ago he had made up a 10 per cent. copper-aluminium alloy with 5 per cent. of nickel, and obtained better results than the authors. He had had occasion to repeat those tests within the last year, and he still obtained similar results, which were rather better than those given in the paper. That meant, that one had to study the best means of making up alloys. One point in the paper itself had very much struck him; perhaps Mr. Greaves might throw a little more light on it. On page 175 it was said : " The alloy which appeared to be hardest on rolling was No. 10 with about $7\frac{1}{2}$ per cent. of nickel and 5 per cent. of aluminium." He could not see why that particular composition should have given a harder alloy than the others. It occurred to him whether it might not have been due to the particular melt containing more aluminium oxide, or something of that sort. The point seemed to require a little more light thrown on it, as it was not at all obvious why that alloy should have been hardest on rolling.

He desired to add his testimony to the value of the paper. It was particularly clear in the way the experiments had been carried out, and in the way they had been tabulated and expressed.

Mr. C. BILLINGTON (Longport) said that he had had considerable experience in casting certain of the alloys mentioned, and he thought from a practical point of view that he could answer Dr. Rosenhain's question with regard to the casting of nickel-aluminium-copper alloys. He found that they cast as easily as alloys of aluminium-copper. His firm had made large castings containing about 10 per cent. of aluminium, 9 per cent. of nickel, and the balance copper, which gave better results than were obtained from the 10 per cent. aluminium-copper. The drawback to the use of these alloys was their excessive shrinking and rapid solidification, as great care had to be exercised in having large heads for feeding, and the difficulty even then was in getting castings of unequal thick-

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nesses sound, and as regards the turning he found that the alloy referred to turned quite as easily as the 10 per cent. aluminium-copper. In making the alloy great care was required to prevent oxidation, so as to get a homogeneous alloy.

Mr. A. E. SEATON (Member of Council) said that some years ago, when aluminium was first appearing in the engineering world as a product that engineers could afford to use, he had made a considerable number of experiments with aluminium-copper alloys, or as it was called then, aluminium-bronze, of various proportions ; but the very strong ones, which seemed most suitable for use, had proved to be very porous. He would like to ask if the addition of nickel closed the grain and made them more useful for such things as fittings for hydraulic work and for very high pressures of steam. He had found that his mixtures would not stand the tests for tightness at all satisfactorily.

Mr. A. PHILIP, B.Sc., Assoc.R.S.M. (Member of Council), said that with regard to corrosion, he noticed the authors had expressed the loss of weight due to corrosion in lb. per square foot per month. These units necessitated the use of three or four cyphers in all the numerical results obtained. It was very desirable that the units in which corrosion results were expressed should be fixed in some way by general agreement. He himself used rather mixed units ; namely grains per square foot per 100 days. He had adopted these in order to obtain a convenient corrosion figure expressed in English units. Taking the authors' results, the largest corrosion which they gave was 0·00091 lb. per square foot per month ; this was equal to 22·7 grains per square foot per 100 days. His own experience was that the loss which resulted from the corrosive action of sea water on metals or alloys, under the most favourable circumstances, never rose as high as 1000 grains, and that the least corrosion which took place was never less than about 0·5, both expressed as grains per square foot per 100 days.

He considered that some unit should be taken which would get rid of the large number of cyphers mentioned in the paper, and which could be generally adopted.

Dr. WALTER ROSENHAIN, F.R.S. (Member of Council), asked to be allowed to add a suggestion to Professor Huntington's remarks with regard to the precautions used in making the alloy. He noticed the authors added aluminium as metallic aluminium to their alloys instead of making a 50 per cent. copper alloy first. That of course was a procedure which was apt to give results not quite as high in tensile strength and in elongation as if the alloy were made first.

Mr. GREAVES, in reply, said Dr. Rosenhain had referred to the corrosion by sea water and to his (the speaker's) term, "greatly reduced." He quite realized that the corrosion of the pure material was already very small, but it was reduced in some cases to one-tenth that of the pure metal, so that after immersion for four months in sea water the alloys

with 5 per cent. of nickel for example came out perfectly bright with a mirror-like surface, whereas the copper-aluminium alloys were always dull. The yield point obtained by the stress-strain diagram was tested in several cases against the results obtained by dividers, and a fairly close agreement was observed. The autographic diagram was also tested against the Ewing extensometer, and it was found to give slightly higher results.

With regard to the machining properties of the alloys mentioned by Dr. Rosenhain and Mr. Billington, there was a noticeable improvement in the 10 per cent. series when 5 per cent. of nickel was present. The alloys of the 5 per cent. aluminium series were very tough, and spirals as long as one wished for could be obtained, especially with 5 per cent. aluminium and 5 per cent. of nickel. The shrinkage in the nickel alloys was always noticed to be very great, although no measurements of shrinkage were made ; but the castings had to be fed to just about the same extent as was necessary with the pure copper-aluminium alloys.

In reply to Professor Huntington, the only reason he could suggest why the $7\frac{1}{2}$ per cent. nickel alloy, with 5 per cent. of aluminium, was harder than all the rest, was that in the annealed state it was found to be harder than all the others that were worked with, on account of the separation of that second constituent which took place on slow cooling. It had been rather a surprise to him to find that the alloy containing $7\frac{1}{2}$ per cent. of nickel with 5 per cent. of aluminium was harder to roll than any with 10 per cent. of aluminium, but it undoubtedly was noticeably harder, and that was borne out by the fact that the Brinell hardness of the slowly cooled material was greater than that of the alloy with the same nickel and 10 per cent. of aluminium.

No porosity tests on the alloys had been carried out, as suggested by Mr. Seaton, but from the fact that the crystalline form was smaller, it was possible that they would withstand hydraulic pressure as well as, or better than, the copper-aluminium. In the 10 per cent. alloys the crystalline form was smallest when 5 per cent. of nickel was present. Afterwards the structure changed.

He had been very much interested in Mr. Philip's suggestion that corrosion should be expressed in grains per square foot per 100 days. An expression in lb. per square foot per month was a very cumbersome one, and a lot of superfluous figures would be avoided if the other method were adopted.

COMMUNICATION.

Professor READ and Mr. GREAVES wrote in further reply that they desired to thank those gentlemen who had taken part in the discussion for their interesting contributions and kind appreciation of the work. The authors were in entire agreement with Dr. Rosenhain that other dynamic tests would have been exceedingly valuable, but unfortunately they had not at their command the necessary appliances for carrying out these tests. The authors regretted that a note on the turning

characteristics of the alloys was not included in the paper ; and they had endeavoured to supply this omission by the following table compiled from their workshop note-book.   The word " tough " was used to indicate the capacity of the material to curl off in spirals during turning.

Table of Turning Characteristics.

No.	Nickel per Cent.	Aluminium per Cent.	Cast.	Annealed Rods.	Quenched Rods.
1	...	10·06	All hard. No. 5 toughest	Hard	Exceedingly hard and brittle.
2	1·04	9·82		,, Tougher	Not so hard and rather tough.
3	2·46	9·88		,, ,, Turns very well	Harder and less tough.
4	4·95	9·94		Harder. Not so tough	Harder and less tough.
5	7·48	9·70		Less hard. Tougher ; best to machine	Not so hard, and tougher.
6	..	5·02	Soft. Tough	Soft. Tough	
7	0·94	5·10	,, V e r y tough	,, Very tough	Similar to an-nealed.
8	2·38	4·94	Slightly harder. Very tough	Slightly harder. Very tough	
9	4·84	5·32	Slightly harder. Very tough	Slightly harder. Toughest	
10	7·31	5·21	Slightly harder. Toughest	Harder. Not so tough	Tougher and softer than annealed.

Professor Huntington thought that Professor Carpenter had obtained better mechanical tests for aluminium-copper than those given in the paper, and suggested that the alleged difference might be due to the presence of alumina.   The results of Carpenter and Edwards' tests were given with those of the authors' in the accompanying table, and it would be seen that the agreement was very close except in the case of 10 per cent. aluminium chill castings.   Even with these results the differences were what might be expected with cast metal owing to the impossibility of having the conditions exactly the same as regards casting temperature, rate of cooling, &c.

The results for the quenched rods, and the cold rolled material agreed just as well as the annealed.   The authors, therefore, had no reason to suppose that the rods were contaminated with oxide.   Possibly slightly better results would have been obtained by the use of the 50 per cent. alloy in melting as suggested by Dr. Rosenhain, but on the other hand Carpenter and Edwards had pointed out that " copper rich alloys can be perfectly satisfactorily prepared from the pure metals, and no advantage is gained by using the 50 per cent. alloy instead of aluminium." *

* *Proceedings of the Institution of Mechanical Engineers*, 1907, p. 92.

Tensile Tests of Pure Aluminium-copper Alloys.

Aluminium per Cent.	Condition.	Yield Point, Tons per Square Inch.	Maximum Stress, Tons per Square Inch.	Elongation per Cent. on 2 Inches.	Reduction of Area per Cent.	Reference.
5·02	Chill casting	5·0	18·73	68·0	58·2	Present paper—Table IV.
5·07	Chill casting	7·1	18·1	60·5	...	Carpenter and Edwards. *Proceedings of the Institution of Mechanical Engineers*, 1907, p. 153.
5·07	Sand casting	4·3	18·1	75·0	...	
5·02	Rods from same ingot annealed at 900°	5·2	22·16	82·5	78·9	Present paper—Table V.
	ingot annealed at 800°	6·0	24·46	79·1	79·0	Read, *Journal of the Institute of Metals*, 1913, vol. x. p. 350.
5·07	Rod annealed at 800°	5·2	23·65	79·0	82·0	Carpenter and Edwards, *loc. cit.*, p. 153.
10·06	Chill casting	11·6	30·43	19·4	27·2	Present paper—Table IV.
9·90	Chill casting	12·4	36·93	30·5	...	Carpenter and Edwards, *loc. cit.*, p. 160.
9·90	Sand casting	11·3	31·70	21·7	...	
10·06	Rods from same ingot annealed at 900°	14·4	25·68	9·0	10·4	Present paper—Table V.
	ingot annealed at 800°	15·6	30·75	5·1	7·0	Read, *loc. cit.*, p. 350.
9·90	Rod annealed at 800°	15·7	28·51	6·5	10·2	Carpenter and Edwards, *loc. cit.*, p. 160.

BRONZE.*

By JOHN DEWRANCE.

THE dictionary meaning of the word " bronze " is a compound or alloy of from 2 to 20 parts of copper to 1 of tin, to which other metallic substances are sometimes added, especially zinc. In times past, the gradually increasing additions of zinc and lead discredited the name of bronze.

In the manufacture of guns, it was found that the best results were obtained by an alloy of 9 parts of copper and 1 part of tin. This became the standard material for the manufacture of guns for many years.

To distinguish this alloy from the inferior mixtures that had previously been supplied under the name of bronze, the description gun-metal was introduced. As time went on the new name gun-metal was no more respected than the old one of bronze, and at the present time any alloy that does not come under the description of pot metal or brass is called gun-metal. As guns are now universally made of steel, it seems desirable to return to the dictionary description and to call all alloys, mainly composed of copper and tin, " bronze."

To the previously mentioned alloy of 90 per cent. copper and 10 per cent. tin, it is very largely the practice to add 2 per cent. of zinc, making 88 per cent. copper, 10 per cent. tin, and 2 per cent. zinc. When tested at atmospheric temperature this alloy gives very excellent results. As a great deal of bronze is used at the temperature of high pressure steam it becomes important to investigate its behaviour at temperatures that correspond.

The researches that have been carried out on non-ferrous metals at high temperature are set out in a paper read before this Institute on January 17, 1912, by Dr. G. D. Bengough.†

The tests, the results of which are given in Figs. 1 to 4, were conducted for the author by Mr. R. H. Harry Stanger.

The heating apparatus was an air-tight tube boiler heated by gas from a ring-burner. The specimen was held in screwed

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* Read at Annual General Meeting, London, March 18, 1914.
† *Journal of the Institute of Metals*, No. 1, 1912, vol. vii. pp. 123–174.

jaws in the centre, both end jaws being insulated, and the boiler was also coated with asbestos.

The testing-machine being a 50-ton vertical Buckton, the weight of the apparatus is carried on the bottom headstock ; the top end of the specimen was held in a plunger which enters the top of the heating apparatus through a broad guide with a sliding fit. Both ends of the apparatus are held in the headstocks by means of spherical holders, thus allowing the whole to find its true vertical axis.

As the specimen is entirely enclosed during the test, some outside means have to be adopted for ascertaining the yield point, if any ; the two ends of the heating apparatus were connected to a Wickstead hydrographic recorder, taking the base line with the beam floating immediately before applying the load after the specimen has attained the necessary temperature.

An experimental specimen was drilled with holes in different positions along the parallel length, and the bulb of a thermometer was inserted in the various positions.

This thermometer was found to agree very closely with another thermometer that recorded the temperature in the air-chamber, and it was therefore inferred that the readings of the thermometer in the air-chamber gave correct readings of the temperature of the specimen.

The percentages of elongation were given by the Wickstead recorder, and are stated throughout as the percentage on 2 inches.

The copper employed in these tests was that which is known on the market as "Best Selected," which has an average analysis as follows :—

							Per Cent.
Copper	.	.	.	.	.	.	99·55
Nickel	.	.	.	.	.	.	0·01
Arsenic	.	.	.	.	.	.	0·026
Lead	.	.	.	.	.	.	0·08
Bismuth	.	.	.	.	.	.	0·004

The tin and zinc were the best commercial quality.

In the first tests made 88 parts of copper were melted in a new crucible, 2 of zinc were added as soon as the copper was melted and allowed a short time to flux the metal, 10 of tin were then added, the whole mass stirred, and the test-pieces

poured at as near the same heat as could be judged by a careful moulder.

The black line on Fig. 1 shows that at atmospheric temperature the 88 copper, 10 tin, and 2 zinc alloy has a maximum stress of 16·35 tons per square inch, and the black line on Fig. 2 shows an elongation of 11 per cent. on 2 inches.

At 400° F. it has a maximum stress of 9·5 tons, and an elongation of only 1 per cent.

At 700° it has a maximum stress of 7 tons, and an elongation of 0·25 per cent.

The first series of tests undertaken was that between 400°
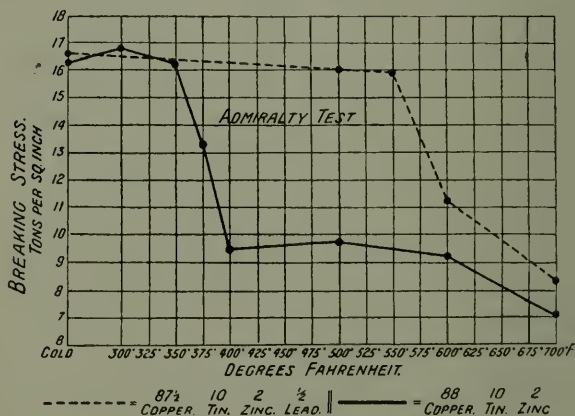
FIG. 1.

and 700° F., and the results were so unexpected that it was thought advisable to re-test some of the broken samples in the cold state, to ascertain if the fault was in the casting of the test-pieces.

For this purpose samples which had failed at 400° F. and 500° F. were turned down and suitably mounted, and when re-tested at atmospheric temperature gave a breaking stress near 18 tons per square inch. Further samples in this same mixture were then prepared and tested at temperatures between atmospheric and 400° F., and the results, embodied on the diagram A, show very clearly that the metal begins to lose its strength above 350° F.

Professor Huntington, in a paper * read before the Institute in 1912, gives, among others, particulars of an alloy of copper 97·673, and tin 2·408 tested cold, and at temperatures up to 870° F.

Having regard to the small proportion of tin, these results are consistent with the results given above.

In the next tests made $87\frac{1}{2}$ parts of copper were melted

ADMIRALTY TEST

- - - - - = $87\frac{1}{2}$ 10   2 $\frac{1}{2}$ ‖   ———— = 88   10   2
COPPER. TIN. ZINC. LEAD   COPPER. TIN. ZINC.
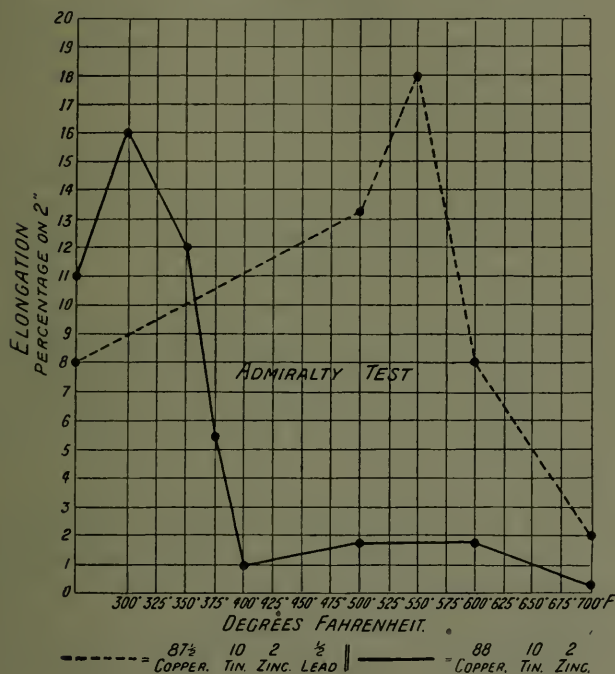
FIG. 2.

in a new crucible, 2 of zinc were added as soon as the copper was melted and allowed a short time to flux the metal; 10 of tin and $\frac{1}{2}$ of lead were then added together, and the whole mass stirred. It will be observed that the only difference between this and the previous experiments is the addition of $\frac{1}{2}$ per cent. of lead at the expense of the copper.

The dotted line in Fig. 1 shows that at the atmospheric

temperature the maximum stress is 16·5 tons per square inch, and the dotted line on Fig. 2 the elongation 8 per cent.

At 550° F. it has a maximum stress of 15·8 tons, and an elongation of 18 per cent.

At 700° it has a maximum stress of 8·25 tons, and an elongation of 2 per cent.

The breaking stress of 11·25 tons per square inch at 600° F. is an average. No actual sample broke at this stress. It was found that some samples tested at this temperature gave results in the region of 16 tons per square inch, and others 7 tons per square inch. From this it may be concluded that 600° is the critical temperature of this alloy.

In a paper read before the International Association for Testing Materials at the seventh Congress in New York, 1912, by I. M. Bregowsky and L. W. Spring, of the Laboratory of the Crane Company, Chicago, the results are given of tests among others of a material called U.S. Navy Gun Bronze " G," which has a composition of 87·6 per cent. copper, 10·4 per cent. tin, 1·31 per cent. zinc, 0·39 per cent. lead—it is also stated to contain 0·11 per cent. iron ; but it is probable that the iron content given is due to using a file for preparing the sample for analysis, as such an alloy ought not to contain such a proportion of iron.

The chart of the test of this metal at first sight appears inconsistent with the results given in this paper ; but this is due to the fact that the tests made were not sufficiently numerous. The first test appears to be at about 80° F., and gives a maximum stress of 15 tons, and elongation of 9 per cent.; the second test is at 300° F., and gives a slightly increased maximum stress of 16½ tons, and elongation of 9·5 per cent. The next test is at 450° F., and gives a maximum stress of 14·75 tons, and elongation of 8 per cent. There is not another test until 600° F., at which temperature the maximum stress is given as 10 tons, and the elongation as 4 per cent.

As previously mentioned, 600° F. is the critical point, and it is unfortunate that there is such a wide gap of temperature between this test and the previous ones, as otherwise the results obtained would have been more consistent with the results given in this paper, and might have given information

as to the slight difference due to that particular composition of alloy tested.

If it is accepted that $\frac{1}{2}$ per cent. of lead raises the maximum
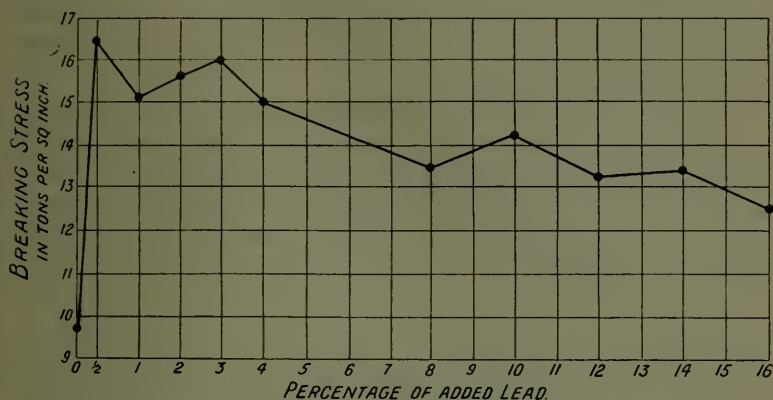
FIG. 3.—Tested at 500° F.

stress at 500° F. from 9·75 tons to 16·5 tons, that proportion of lead becomes an essential ingredient in bronze, that is,
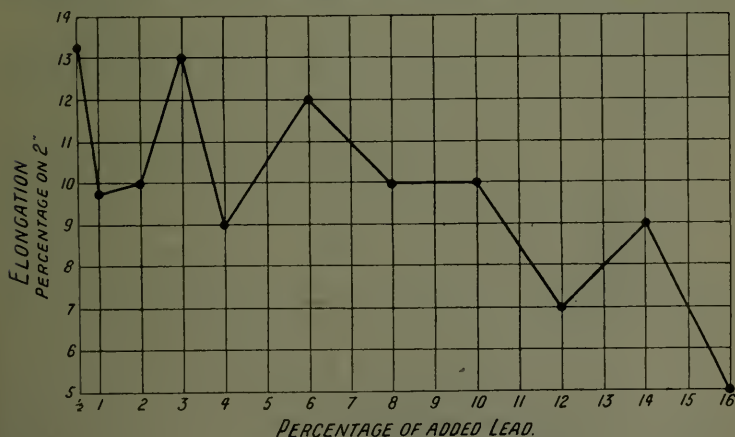
FIG. 4.—Tested at 500° F.

subjected to temperatures above 350° F. It also becomes necessary to inquire whether any further advantage can be gained by adding a larger proportion of lead.

Figs. 3 and 4 show that this is not the case; but it is

surprising that with so large a proportion as 16 per cent. of lead the maximum stress at $500°$ F. is $12\frac{1}{2}$ tons as against 9·5 tons without any lead. In making these experiments the lead was added at the expense of the copper. So the last result would be 72 per cent. copper, 10 per cent. tin, 2 per cent. zinc, 16 per cent. lead.

In making the foregoing experiments the question arose as to whether any of the results were due to the absorption of oxygen from the atmosphere by the alloy when in a molten condition. It is difficult to determine the content of oxygen in bronze, so the following experiments were conducted with best selected copper :—

Experiment No. I.

A new 100-lb. plumbago crucible was taken. As soon as the copper was sufficiently hot an ingot was cast, and the rest of the metal was returned to the fire for an hour, when a second ingot was cast, and the same thing repeated for the third ingot.

There were thus three ingots cast from the same crucible at intervals of one hour.

On analysis the oxygen contents of the three were as follows :—

	Oxygen per Cent.	Cuprous Oxide per Cent.
No. 1	0·032	0·285
,, 2	0·272	2·499
,, 3	0·404	3·605

Experiment No. II.

Two new plumbago crucibles containing 100 lb. of B.S. copper were taken, and $\frac{1}{4}$ lb. of 10 per cent. phosphor copper was added to one, and 0·6 oz. aluminium to the other, as deoxidizers. The copper was covered with glass, so that when molten no air could come in contact with it ; and three ingots were cast at intervals of one hour, as in the former experiment, the glass being left on during the casting.

Oxygen Contents on Analysis.

		Oxygen per Cent.			Oxygen per Cent.
Aluminium as deoxidizer	No. 1	0·084	Phosphorus as deoxidizer	No. 1	0·036
	,, 2	0·080		,, 2	0·036
	,, 3	0·092		,, 3	0·036

Both sets of results show that if the metal is kept from contact with the air when molten no oxygen is picked up ; and if this precaution is not taken each melting will result in an increase in the content of oxygen, and this conclusion was accepted and acted upon when making the following experiments. The products were not analysed for oxygen on account of the previously mentioned difficulty of such analysis.

EXPERIMENT No. III.

One new plumbago crucible containing 100 lb. of $87\frac{1}{2}$ per cent. copper, 10 per cent. tin, 2 per cent. zinc, and $\frac{1}{2}$ per cent. lead was covered with glass to exclude the air and melted ; another exactly similar charge was allowed ample opportunity to pick up oxygen by being repeatedly skimmed and left standing in the air after being taken from the fire.

Test-pieces, and a heavy flange casting with a light and thin nipple on each side, were cast from each crucible.

The flange castings were broken, and examined very carefully, and both appeared as sound as it is possible to get a casting. The test-pieces gave the following results when tested cold and under heat :—

	Temperature.	Maximum Load in Tons per Square Inch.	Extension on 2 Inches, per Cent.
First charge covered with glass to exclude oxygen . .	Cold At 500° F.	15·17 13·73	9·0 10·5
Second charge uncovered to absorb oxygen . . .	Cold At 500° F.	16·55 15·15	12·5 14·0

Experiment No. IV.

To complete the above results Experiment No. IV. was made, which consisted in casting a similar flange and test-pieces in " twice-run " metal. The flange casting again proved sound, and the test-pieces gave the following results :—

	Temperature.	Maximum Load in Tons per Square Inch.	Extension on 2 Inches, per Cent.
Metal twice run without any precaution to prevent absorption of oxygen . .	Cold	15·19	8
	At 500° F.	16·15	14

The foregoing experiments point to the conclusion that in an alloy of $87\frac{1}{2}$ per cent. copper, 10 per cent. tin, 2 per cent. zinc, and $\frac{1}{2}$ per cent. lead, no benefit results from the deoxidation of the metal, or in taking special precautions to prevent the metal absorbing oxygen.

There is another feature of considerable interest in these alloys.

When the alloy that is free from lead is turned in the lathe the turnings have a considerable curl upon them (see sample No. 1).

The addition of $\frac{1}{2}$ per cent. of lead materially reduces the length of the turnings (see sample No. 2).

It would naturally be supposed that this feature is due to the fact that without the lead the alloy has an elongation of 11 per cent. on 2 inches, and with the addition of the lead the elongation is reduced to 8 per cent., and that the turnings break off more readily for this reason.

The same test-pieces from which the turnings (samples 1 and 2) were made when cold were then heated and turned at 550° F., and as will be seen by samples 3 and 4 the alloy without the lead still presents the same curly appearance, and the turnings from the alloy containing the $\frac{1}{2}$ per cent. of lead are very little longer than the turnings produced in the cold.

The elongation of the alloy containing $\frac{1}{2}$ per cent. of lead, as will be seen by the chart, is at 550° F., 18 per cent. on

PLATE XV

| Tested Cold. | Tested at 400° F. | Tested at 500° F. | Tested at 600° F. | Tested at 700° F. |

								Per Cent.
Copper	.	.	.	.	.	.	.	. 88
Tin .	.	.	.	.	.	.	.	. 10
Zinc .	.	.	.	.	.	.	.	. 2

| Tested Cold. | Tested at 500° F. | Tested at 550° F. | Tested at 600° F. | Tested at 700° F. |

								Per Cent.
Copper	.	.	.	.	.	.	.	. $87\frac{1}{2}$
Tin .	.	.	.	.	.	.	.	. 10
Zinc .	.	.	.	.	.	.	.	. 2
Lead .	.	.	.	.	.	.	.	. $\frac{1}{2}$

2 inches ; whereas the elongation of the alloy without the lead falls at this temperature below 2 per cent.

As lead has such a marked effect on bronze, enabling it to be used without loss of strength up to 550° F., it seems reasonable to expect that some other metal might be added that would enable the bronze to withstand even higher temperatures.

With this object in view 87·25 per cent. copper was melted in a new crucible, and 0·25 of silver was added when the copper was melted, and the whole mass stirred. Ten per cent. of tin and 2 per cent. of zinc, and ½ per cent. of lead were then added and again stirred. Two test-pieces were prepared and tested at 700° F. One test-piece gave a maximum load of 8·11 tons, the other 8·75 tons.

The extension in neither case exceeded 0·5 per cent. on 2 inches. The maximum load is practically the same as without the silver, and the extension not so good.

Nickel is not very promising, as in small proportions it seems invariably to liberate some occluded gas on cooling, and produces very porous castings.

Aluminium is objectionable, because in even small proportions it seems to add materially to the amount of the contraction of the casting on cooling.

Iron is strongly objected to in fine bronzes, as it combines with the tin and separates out into hard masses in the casting.

The subject seems to call for further research, as it is possible that small proportions of some of the rarer metals may have a beneficial effect.

With the present use of superheated steam it is very desirable that a bronze should, if possible, be produced that can be used with safety at 700° F.

DISCUSSION.

Sir Henry J. Oram, K.C.B., F.R.S. (President), said that the members were very much indebted to Mr. Dewrance for bringing this important subject forward.

In the absence of further information, there was some difficulty in assessing to what extent deductions could be safely drawn from the figures. For instance, the author did not state whether the spots on the curves were generally the results from single test-pieces or whether they were an average of several tests. In all the tests carried out at the dockyard, the average of results from three specimens was generally taken. Very different results, of course, were obtained if the maximum of each set of three were taken.

Then again, although the alloys were mixed in given proportions, it was not stated whether the test-pieces were subsequently analysed to show what their actual compositions were when tested. For instance, he (the speaker) understood that lead had a tendency to settle or separate out, and there might conceivably have been considerable differences. The Admiralty in 1910 at Portsmouth had made a large number of tests on the metals mentioned, and also on similar ones, and he would proceed to give the particulars of them. The lead was added in rather a different proportion to Mr. Dewrance's lead; Mr. Dewrance took off an equal amount of copper for any lead that he added. In the experiments to which he (the speaker) referred, lead was added in a different way. The 88–10–2 composition was taken, and so much per cent. of lead was put in in addition. In the 88–10–2 composition, although 1 per cent. of lead was added, on analysis the amount was found to be 0·91 per cent. When 1·25 per cent. of lead was added, Mr. Arnold Philip found that the actual amount when tested was 0·92. Again, 2 per cent. of lead was reduced on analysis to 1·75 per cent.

He (the speaker) presumed also that the temperatures of the melted alloys and the times for cooling the cast specimens were in as close an agreement as possible, in view of the comparative results aimed at, and the possible effects of variation due to heat treatment and perhaps oxidation. The mixture containing ½ per cent. of lead was of particular importance, in view of the consistently high results given by it at all temperatures up to 550° F., both in maximum stress and ductility. Most of the experiments made by the Admiralty had been carried out at a temperature of 450° F., and not 500° F. or higher, because at the time the experiments were made it was not desired to know the effect of very high temperatures such as would be given by superheated steam. It was desired to ascertain the effect of ordinary temperatures of steam corresponding to the pressures then being used, so that 450° was quite high enough. He might say that the tendency of the results given by the experiments were in general agreement with figures given by Mr. Dewrance in his curves, but when details were come to there were very extraordinary differences between

the Admiralty results and Mr. Dewrance's. He (the President) quite agreed that the presence of $\frac{1}{2}$ per cent. of lead did improve the qualities of the material. In the Admiralty experiments carried out in 1911— taking one particular set of experiments—the lead varied from 0 to 2 per cent. The lead increased by $\frac{1}{4}$ per cent. stages, starting at $\frac{1}{4}$ per cent. and then $\frac{1}{2}$ per cent., and so on.

Although the results were in general agreement with what Mr. Dewrance had obtained on the diagrams, he might give some examples of variation which showed that what he had previously mentioned was correct, namely, that very systematic and lengthy series of experiments were required if any satisfactory light was to be thrown on this important question. Taking the ordinary Admiralty gun-metal alloy—which, it would be thought, there was no doubt whatever about; it was a well-known composition, 88–10–2—Mr. Dewrance obtained 16·3 tons per square inch tensile strength in the cold condition, as shown on the top diagram on the wall. The experiment made by the Admiralty in 1911 gave 14·5 tons. He might add that the 1911 experiments were made after certain other experiments had been concluded in 1909 and 1910, but the Admiralty had not been satisfied with the results obtained, and ordered the dockyard to make further careful tests, so as to endeavour to ascertain the truth.

The 1911 experiments were conducted with great care, and were quite different from the 1910 experiments. He believed they might be accepted as being the most accurate experiments made by the Admiralty. At 450°, which was the actual temperature at which the Admiralty experiments were made, one could not tell exactly what Mr. Dewrance's figure would have been, but taking it from the curve which he had given, the tensile strength was reduced to 9·7 tons, whereas the Admiralty experiments gave 13·6 tons, so that, in the latter case, the reduction was not very great. He must say, however, that the 1910 experiments did show a very considerable reduction, more in the nature of Mr. Dewrance's figures. Still keeping to the gun-metal without lead, the elongation obtained by Mr. Dewrance was 11 per cent. The Admiralty figure was 14 per cent. Then, a very striking difference occurred. At 450° on Mr. Dewrance's curve the elongation was under 2 per cent. as would be seen from the diagram, but the extraordinary thing was the Admiralty's experiment gave 13·9 per cent. Turning to the metal containing $\frac{1}{2}$ per cent. of lead, there was more agreement between Mr. Dewrance's experiments and the Admiralty experiments. In the cold condition, Mr. Dewrance's figure was 16·6 tons, and the Admiralty figure was 15·1. When the temperature was raised to 450°—he must take that from Mr. Dewrance's curve again—it was 16·2 tons and the Admiralty experiments gave 14·8. Therefore there was a reduction, in the case of Mr. Dewrance's experiment, of 0·4 tons, and, in the case of the Admiralty experiments of 0·3 tons, so that was a very substantial agreement. Coming to the elongation, considerable differences are again found. In the cold condition Mr. Dewrance obtained 8 per cent., whereas the Admiralty obtained 18·5 per cent., and at 450° Mr. Dewrance got 12·2 and the Admiralty got 20·3. Those differences

P

were very remarkable, and wanted some further elucidation. He did not think for one moment that Mr. Dewrance's results were incorrect, nor is it probable the Admiralty were wrong; at any rate he would assume that both sets of results were accurately taken, the differences arising possibly from different methods of preparation and treatment of the specimens tested.

Professor HUNTINGTON inquired how they were treated.

The PRESIDENT said he had not that information with him, but he would add it later.*

The PRESIDENT said he might add that the Admiralty officers took special precautions as to melting. The temperatures were kept as low as possible consistent with the pouring of the metal, and the specimens were all analysed, after they were cast, by the Admiralty chemist to ascertain the actual percentage of lead.

The differences were very remarkable, and he simply mentioned them in order that Mr. Dewrance at some future time might repeat his tests and tell the Institute with certainty what was the truth of the matter.

He would like to mention one feature which had been brought out in the dockyard experiments of 1911, and that was the unevenness of the results as the lead varied. For example, the maximum stress with $\frac{1}{4}$ per cent. of lead was less, both cold and at 450° F., than with either no lead or with $\frac{1}{2}$ per cent. of lead, and a similar result was noticed with $1\frac{1}{4}$ per cent. of lead in comparison with 1 per cent. and $1\frac{1}{2}$ per cent. of lead. How far such observations might have been due to some of the causes touched on at the commencement of his remarks could not at the present time be stated, but those results were certainly observed. He would like to point out that Mr. Dewrance obtained similar differences at 500° with his higher percentages of lead; that would be found in Figs. 3 and 4 at 1, 8, and 12 per cent. That seemed to suggest the desirability in future experiments of investigating the results with smaller variations than 1 per cent. of lead. Another cause which might affect the result was the period during which the specimen might be exposed to the high temperature. It would be useful if results at a certain temperature from specimens of the same composition were obtained from tests in which the test-pieces were subjected to the temperature in question for periods of varying and considerable duration before the application of the breaking stress. In the experiments at Portsmouth, after preliminary warming outside the furnace, the specimens were exposed to the temperature for one hour.

Finally, with regard to experiments 3 and 4 carried out by Mr.

* They were heated in air in a small compartment screened off from the top of a larger vessel or furnace made of copper, the latter being heated by a Bunsen gas ring at its lower part. The specimen being tested was held in the grips of the testing machine, passing through the sides of the small compartment, and was (after preliminary heating outside above the apparatus), when placed in the grips, subjected to the required test temperature for 60 minutes before the test was applied. The temperature of the air adjacent to the specimen was measured by a thermometer fixed in a suitable position, and was taken as the temperature of the specimen.

Dewrance on the question of oxidation, these seemed to contradict the more or less generally accepted impression that tin oxide might be formed, and that it had a weakening effect; and some confirmation of those experiments seemed to be desirable.

He quite agreed with Mr. Dewrance's concluding remarks as to the desirability of further investigation in order to find some alloy that could be successfully used in connection with superheated steam; and it was to be hoped that Mr. Dewrance himself would be able to carry that out at some early date.

He was afraid he had sketched out rather a long programme for Mr. Dewrance in order that the subject might be thoroughly elucidated, but he believed that such a long programme was necessary before the truth was discovered; he was certain it was not known at the present time.

Mr. G. A. Boeddicker (Vice-President) said that Mr. Dewrance made rather a sweeping assertion as to the addition of nickel to bronze: he had said there was no use in small quantities on account of the great quantity of gases which it set free. He (Mr. Boeddicker) would like to know how Mr. Dewrance had been using the nickel, because he (the speaker) certainly did not find that result when the addition of nickel was properly made.

Dr. Stead, F.R.S. (Middlesbrough), said that we were still in ignorance as to why small quantities of lead had such a wonderful effect as Mr. Dewrance had shown it had.

He suggested that it would greatly encourage research if the manufacturers throughout the country were to send queries to the Institute of Metals whenever they came across phenomena connected with their industries which required explanation. If this were done, and a list of such questions were published by the Institute from time to time, much research would most surely follow.

Professor A. K. Huntington, Assoc. R.S.M. (Past-President), said that there was one point with regard to the method of investigation pointed out in the paper about which he might add a word of caution. On p. 215 it was said: " An experimental specimen was drilled with holes in different positions along the parallel length, and the bulb of a thermometer was inserted in the various positions." For many years he used a thermometer in testing the temperatures above the atmospheric, and he had found that the results were absolutely unreliable unless one had a good conducting medium in the hole in which the thermometer was inserted. At one time mercury had been used, but he had found in dealing with brass alloys and copper-tin alloys that that often led to a good deal of trouble. He substituted for it a low melting white metal containing cadmium, and he never had any more trouble. Until he inserted, however, a little quantity of a low melting white metal into the place in which the thermometer rested, in that way making perfect contact with the bar, trouble had always arisen. He would suggest to Mr. Dewrance whether it was not possible that that might rather invalidate the state-

ment : " This thermometer was found to agree very closely with another thermometer that recorded the temperature in the air-chamber."   It was quite possible that the thermometer in the hole was recording only the temperature in the air-chamber, and not the real temperature of the bar.

There was one other point.   On pp. 220 and 221 the author stated in his table of "Oxygen Contents of Analysis" that with aluminium as a deoxidizer he obtained up to 0·092 per cent., and that when phosphorus was used as a deoxidizer he got 0·036.   That seemed to him (the speaker) to point to the fact that when the aluminium had been used some of the aluminium oxide had remained behind and had been counted as so much oxygen in the analysis.   It might do a good deal of mischief in making the casting unsound, but it was not quite the same thing as having oxygen present in the copper.   When phosphorus was used a fluid product was formed which floated up, and very much less oxygen was found in the metal.   He did not think there was much doubt that one had deoxidized just as much as the other.   There was another point in connection with that.   At the bottom of p. 221 the author had given the result of covering the charge in one case and not covering it in the other, but he had overlooked the fact that he had a deoxidizer there in the form of zinc ; he had 2 per cent. of zinc.   That would deoxidize in both cases, and it was quite possible that the difference in the result which he obtained when the crucible was uncovered was really due to a certain amount of oxidation of zinc, reducing the total quantity remaining in the alloy.

Mr. C. BILLINGTON (Longport) inquired whether the temperature had been taken of the metals at the time of pouring, as that might account for the difference between the experiments made at Portsmouth and those made by Mr. Dewrance, also the shape of the bars and how they were cast, as this would have a decided effect upon the results obtained.

Mr. J. S. G. PRIMROSE (Ipswich) said the paper was similar to one on "The Practical Heat Treatment of Admiralty Gun-metal," which had been submitted to the Institute a year ago by his brother and himself. One point which he would like to raise, and which had not been mentioned so far in the discussion, was that the paper was a little lacking in photomicrographs.   If Mr. Dewrance had included some micrographs of the metals after they had been raised to the temperatures mentioned and then tested, that would possibly have afforded some clue to the reason for the results obtained.

The question of heating the furnace and of maintaining the temperature of the space in which the metal had to be treated and there tested, was undoubtedly a very important one.   Instead of the gas-burner, which would heat the metal in an atmosphere of harmful gases, he considered it might have been better to adopt the practice of using an electric furnace to enclose the whole specimen and grips, so that the temperature might be maintained with absolute uniformity.   That was a point of which Mr. Dewrance might take note—to state if the temperature was quite uniform throughout the whole length of the furnace.

His brother's and his own researches differed from Mr. Dewrance's in so far as the tests which they had carried out dealt with gun-metal or zinc-bronze containing less than 0·2 per cent. of lead. The annealing of this alloy very clearly indicated that even this small quantity of lead was not ultramicroscopic, since after heating to 700° C. for half an hour, the structure showed the absorption of·the eutectoid (formed on cooling from fusion), but the lead in it had been left as little isolated patches, discernible under suitable magnification.

Another point which Mr. Dewrance had not mentioned, and which might account for the difference between the tests carried out by the Admiralty and his own tests, was the way in which the alloys had been cast. The temperature of pouring was a very important matter also, as had been shown in his brother's paper of 1909, but he especially wished to ask Mr. Dewrance to state in what kind of mould the test bars were cast. The figures given in their joint paper last year showed that the tensile strength of Admiralty gun-metal might vary from 15 to 18·6 tons per square inch, depending upon how it had been cast, that was to say, whether in dry sand or green sand, in a chill mould by itself or in a chill attached to a great mass of metal. These various methods of casting had a great effect on the structure of the normal metal and also upon the behaviour of the alloy under heat treatment.

The question of melting under various coverings was an important one, because he had every confidence in saying that silicon to a small extent could be taken up by gun-metal which had been melted under glass as a flux. Silicon, even in a very small proportion, was almost sure to have some hardening effect not only on the alloy in the normal cast state, but also on the condition of the metal at the higher temperatures.

Dr. C. H. Desch (Glasgow) said that there were two points in Mr. Dewrance's very interesting paper on which he would like to comment. The improvement which was supposed to be effected by the presence of lead seemed to him to be contrary to what hitherto had been the general experience in regard to the alloys mentioned. Tests had been made by Guillet, for example, at high temperatures, in which he found the influence of lead always deleterious. It was quite true that Guillet did not make any tests, as far as he (the speaker) knew, with so low a percentage as $\frac{1}{2}$; but with 1 per cent. the influence was distinctly harmful, and so fully had he (the speaker) believed that, from many tests which he had previously seen, that in lecturing to foundrymen he had warned them of the danger of lead in any bronze or gun-metal which was intended to be used at a high temperature, as, for instance, for superheated steam. If he had been wrong he was afraid he had been unintentionally misleading workmen. It struck him that perhaps part of the improvement mentioned with $\frac{1}{2}$ per cent. of lead, was simply due to some cleaning influence exerted by the lead on what was not a particularly good metal to begin with. He did not know, from what the President had said, whether the average results obtained at the Admiralty were as low as those that he had mentioned, but he (the

speaker) had seen 88–10–2 metal with very much better qualities than that, giving 18 to 20 tons, and not 10 per cent. elongation, but 30 per cent.—and that with very fairly large castings.   That metal, he thought there could be hardly any doubt, would be injured by the addition of lead.

With regard to the behaviour of the alloys mentioned with superheated steam, he had lately had an opportunity of seeing some very important experiments which had been going on for some years on the influence of high temperatures on alloys.   It had been found that many alloys tested at the temperature of superheated steam would behave quite well, but if kept in actual superheated steam for a month and then tested either hot or cold, they would be as rotten as carrots and would break off quite short.   The influence of superheated steam in that case was not one merely of temperature, but of chemical action.   It did not seem safe to infer the behaviour of an alloy in superheated steam from its conduct when merely tested hot after heating in air.

Mr. Arnold Philip, B.Sc., Assoc.R.S.M. (Member of Council), said that he had had some exceptionally high tensile gun-metal of Admiralty composition sent to him for chemical test, as it was thought desirable to ascertain if there was any chemical reason which would explain the unusually high results.   When analysed all the castings showed a certain percentage of phosphorus.   He thought that perhaps in the same way the presence of phosphorus might explain some of the high results to which Dr. Desch had referred.

Dr. Desch said that the specimens he had referred to contained no phosphorus.

Mr. Arnold Philip, continuing, said that the amount of phosphorus in the samples to which he referred was only of the order of ·02 per cent.   There was one other matter to which he wished to refer.   He had been much interested to see that Mr. Dewrance had called attention to a point which he (the speaker) did not remember having previously seen referred to in print, but concerning which Dr. Desch, very likely, being an encyclopædia of reference, might know.   Mr. Dewrance said that iron was strongly objected to in fine bronzes, as it combined with the tin and separated out into hard masses in the casting.   As he had said, he did not remember having seen that previously in print, but it agreed with the Admiralty's experience—that if alloys containing tin and iron were cast too hot and allowed to cool slowly during the liquid state, there was a separation out or segregation of metallic crystals containing high percentages of iron.   He would be extremely grateful to Mr. Dewrance if he could say something further about that point.

The fact that this segregation had occurred was shown by the chemical analysis of a casting of a bronze containing tin 1 per cent., iron 1 per cent., copper 58 per cent., and zinc 40 per cent., which had been cast at too high a temperature, and in which the percentage of iron was found to

vary from 0·6 per cent. to 4·0 per cent. from point to point. In another case an ingot of bronze containing tin 0·75 per cent., iron 1·0 per cent., copper 50 per cent., manganese 2·0 per cent., nickel 2·0 per cent., and zinc 44·25 per cent. was taken and a plate $\frac{1}{10}$ inch thick was cut from it. This was submitted to corrosion in sea water for three months, and was found to have lost weight at the rate of 61 grains per square foot per 100 days. The corrosion appeared to have taken place uniformly over the surface of the plate, which did not show any markings of iron rust. A casting was then made from the ingot at too high a temperature and from this casting a plate of metal was cut similar to the plate from the original ingot, and this was also submitted to the corrosive action of sea water for three months under precisely similar conditions, and it was found to have lost weight at the rate of 78 grains per square foot of surface per 100 days, and, moreover, showed very marked rust spots of an irregular shape but of a size up to as much as half an inch across, on its surface. These rust marks appeared on both sides of the plate of metal exactly opposite to one another, and as the plate was $\frac{1}{10}$ of an inch thick, this demonstrated that the segregations of the iron containing material were of considerable size. He had been most interested in Mr. Dewrance's reference to this question, and trusted that he would be able to throw some further light on it.

Mr. A. E. SEATON (Member of Council) said that he desired to refer to, he would not say a common experience, but an experience which was commoner formerly than it was at the present time. It used to be pretty well known amongst those who had to employ mild steel in earlier days, that unless there was a fair amount of lead added to the bronze, trouble ensued with hot bearings. There was no doubt at that time, as now, that 2 or even 3 per cent. of lead added to bearing metal made it decidedly the better. At one time lead was looked upon as a public enemy, but now everybody was proving what a good friend it really was. He did not know whether it was due to the result of Sir William Ramsay's investigations, and that lead was not really always lead, but something else ; that in this course of transition the lead of to-day was not the same as the lead of yesterday.

He supported heartily Dr. Stead's recommendation that, when practical men did find curious difficulties, they should report them to the Institute.

Mr. E. J. BOLTON (Stoke-on-Trent) said that there was one matter which had occurred to him from a practical point of view. He noticed that best selected copper had been used to make the test-pieces. In comparing the Admiralty tests with those of Mr. Dewrance, it seemed to him that, unless it was known for certain that in both cases the same brand of best selected copper had been used, just the impurities in the copper alone would be quite enough to make a considerable difference in the physical tests. He did not know what effect it had actually on the crystalline structure—that was beyond him—but he did know that different brands of best selected copper could make a very considerable

difference in the physical tests of either bronze or brass. It seemed to him that, unless the bronze or gun-metal had been made of electrolytic copper and also electrolytic spelter, there would be quite enough impurity in either one of those metals to have made the present results unreliable for comparison with those which had been made some years previously by the Admiralty.

The PRESIDENT, before calling on Mr. Dewrance to reply, expressed the pleasure which the members all felt at seeing an actual manufacturer reading a paper at the Institute. It was quite out of the common order of things, and the members welcomed Mr. Dewrance in that capacity very much indeed.

Mr. DEWRANCE, in reply, thanked the members very much indeed for the very kind way in which they had received the paper, and for the very interesting discussion which it had brought out. The fact that his own results differed from those which were obtained in the dockyards was somewhat unfortunate, and he quite agreed with the President when he said that it would be very desirable if, after what had occurred in the discussion, he (the speaker) had a new set of tests made to confirm the results.

With regard to analyses, he did have analyses made of three of the samples after the test, and he had obtained from one of the $\frac{1}{2}$ per cent. of lead samples an analysis showing copper, 87·47 ; tin, 10·55 ; zinc, 1·52 ; and lead, 0·46. In another sample there was 87·24 of copper, 10·42 of tin, 1·93 of zinc, and 0·41 of lead. Another sample, without the lead, gave 87·54 of copper, 10·5 of tin, 1·87 of zinc, and 0·09 of lead. He need not apologize for the fact that in each case the tin was higher than was actually put in, because he thought it was well recognized that that was the usual result of chemical analysis, even when carefully made. It would be seen that 0·46 in one case, and 0·41 in another, was a very close result for $\frac{1}{2}$ per cent. of lead added to the metal. With regard to the test-pieces, there was no doubt whatever about it that two test-pieces could hardly be compared unless the exact composition of the metals was known, also the exact size of the casting from which the test-piece had been made, the temperature at which it was poured, the rate of cooling, and all such different points. As a matter of fact, the test-pieces which were produced were cast in green sand from a pattern which had approximately the shape of the test-piece, and had very little to be turned off. It was quite probable that the dockyard experiments were made from a stick of metal, probably of a considerable size, and a great deal might have been turned off. That would account for the difference between 14 and 16 tons to the square inch. The number of test-pieces which had been used on some of the critical stages amounted to five or six tests one after the other, and sometimes two or three were obtained in very close agreement. The others showed some causes for their differences, and then the average of those which were most closely in agreement was taken. In no case had a single result been taken. The tin oxide which was formed in a pot of metal unques-

tionably was injurious. All he wanted to bring out in the paper was that in the 88–10–2 metal, with the presence of the zinc, it was not necessary to take any very special precautions to prevent the metal oxidizing, ordinary care seemed to be quite sufficient; but on that point he was quite open to conviction if anybody had any different results, because actually what was the cause of a bad casting was very difficult sometimes to explain.

Dr. Stead's suggestion, that all problems should be sent to the Institute, was a very good one. Dr. Stead had also inquired why the lead had accomplished the result mentioned. He (the speaker) was afraid he could not really suggest an explanation. He had put the results before the Institute in the hope that he would have received that information. He hoped it would do as Dr. Stead suggested, stimulate youthful investigators to come forward and explain the matter.

Professor Huntington had suggested that there was an inaccuracy in the heating of the test-piece. There was no doubt about that, but he (the speaker) did not see that the professors and members of the Institute fully agreed as to exactly the right way of heating test-pieces. On that point also he wanted a certain amount of information before he carried out further tests.

Mr. Billington had asked a very important question as to the temperature at which the metal was poured. A pyrometer had not been used. He had used one or two sorts of pyrometers, but he had really found considerable difficulty in getting any reliable results from them. The best method of judging the temperature of bronze which he had found, and the most practical, was to shake the crucible and to observe the way the bronze fell off the side of the crucible. That was a more rapid method than any pyrometer which could be possibly used.

Mr. Primrose had suggested that photomicrographs would have added to the interest of the paper. In that he fully agreed, and was sorry they had not been included. As the matter was rather crude and subject to further research, he hoped that that deficiency would be supplied on some future occasion.

The point with regard to the absorption of silicon in the metal was exceedingly interesting and a subject which he would certainly look into.

Dr. Desch mentioned the shock tests. That also was an extremely interesting suggestion, and one which he would certainly have carried out. The fatigue test might also be applied to see whether the physical properties in that respect suffered by the addition of the lead.

With regard to the effect of superheated steam on the bronze itself, he might say that he had put a test-piece into superheated steam at 700° F. for, he thought it was, three months, and then tested it against another test-piece poured out of the same crucible, and he had found no practical difference in the result.

Professor HUNTINGTON inquired what metal it was.

Mr. DEWRANCE replied that it was the ordinary Admiralty bronze which was being employed at the particular time.

Mr. Philip had mentioned iron-tin alloys and the fact that his (the speaker's) results agreed with Mr. Philip's.   He had made a large number of experiments on that point some years ago, and by using alloys containing a large percentage of iron, he had been able to drill out or cut out little pieces of what was evidently that alloy ; but he had not the analysis in his mind.   It was an alloy containing quite a large percentage of iron—so much iron that it rusted very freely—and it was evidently something which had segregated out from the rest of the metal.

The suggestion made by Mr. Bolton, that the impurities of the material might account for a good deal of the differences in the results, was also a very interesting one.   If Mr. Bolton could communicate any experience he had had in such of the impurities as were specially evil and which should be avoided, it would be very gratefully received by himself and many members of the Institute.

COMMUNICATION.

Mr. G. A. BOEDDICKER (Vice-President) wrote to suggest the addition of nickel in the form of 50 per cent. cupro-nickel, as this could be prepared well carbonized and would dissolve in the alloy much more readily and would make it unnecessary to overheat the bronze, which, together with the presence of oxygen, would probably account for the porosity of the casting.

THE MICRO-CHEMISTRY OF CORROSION.*

Part II.—THE α-ALLOYS OF COPPER AND ZINC.

By SAMUEL WHYTE, B.Sc., and CECIL H. DESCH, D.Sc., Ph.D.

(Respectively Assistant and Graham Young Lecturer in Metallurgical Chemistry in the University of Glasgow).

The experiments described by the authors in Part I. of this investigation † were confined to the β-solid solutions of the copper-zinc series, the original intention having been to examine the alloys of the Muntz metal class, containing both the α and β constituents. As the corrosion of such alloys begins always in the β-areas, it was thought advisable to investigate the micro-chemical nature of the process in this constituent first, before proceeding to the more complex case. This selection had the disadvantage that the alloys examined were of little technical importance, and any results obtained from the experiments could not be directly employed to establish any practical conclusions. In this second part, the alloys dealt with are those which find the most important technical applications.

The use of an external electromotive force for the purpose of hastening corrosion undoubtedly introduces a factor which is not present in the ordinary conditions of unassisted chemical corrosion, but is unavoidable for the particular purpose which the authors have in view. Chemical corrosion is too slow and too irregular, too easily affected by accidental and uncontrollable changes in the conditions, to lend itself to investigation on the small scale in the laboratory for the purpose of obtaining quantitative data. Chemical corrosion is thus more satisfactorily studied by means of experiments on the large scale, continued over long periods, as in the elaborate series now in progress under the auspices of the Corrosion Committee of this Institute.

Nevertheless, it appears that experiments on a small scale may throw some light on the *mechanism* of corrosion, even when it takes place under conditions excluding the presence of an external electromotive force. The comparison of laboratory experiments with observations of corroded specimens of copper-zinc alloys from works and shipyards has convinced the authors that all corrosion of these alloys is preceded by dezincification, but that, where the action proceeds slowly and there is free access of gaseous or dissolved oxygen, the spongy residue of copper may be converted into oxide as fast as it is formed. This, it is believed, is the origin of the adherent layer of copper oxide which is often found on the corroded surface of brass. The evidence for this view is given in the present paper.

The method of experiment employed was modified slightly in order to ensure greater accuracy, but was in all essentials the same as that described on p. 307 of the first paper. The cathode, instead of being a loop of platinum wire, was made of fine platinum gauze, 1 centimetre square, having a vertical platinum wire welded to it for the purpose of attachment to a support. The Classen stand for electrolytic analysis was found to be most convenient for holding the cathode in place, the distance between the surface of the specimen and the cathode being adjusted by interposing a sheet of plate glass 5 millimetres thick, and bringing the cathode gauze into contact with it and then withdrawing the glass.

The analytical methods were the same as those described previously. Lead, which was not included in the earlier experiments, was removed from solution by electrolysis with a small platinum gauze anode, on which the lead was deposited as peroxide. This was then dissolved in a little nitric acid, evaporated to dryness, and dissolved in water. On the addition of 0·5 cubic centimetres of a solution of hydrogen sulphide, a yellow coloration was produced, which was compared in an Eggertz tube with that given under the same conditions by a standard solution of lead nitrate. No special difficulties were encountered in the course of the analytical work.

Record of Experiments.

In this series of experiments, four alloys were used, one of which was examined in the annealed and also in the unannealed condition. The analyses are given in Table IX. The figures in the last two columns give the composition of the equivalent copper-zinc alloys, determined by Guillet's method, the coefficients of equivalence of tin and lead being taken as 2 and 1 respectively.

Table IX.

Alloys.	Copper, per Cent.	Zinc, per Cent.	Tin, per Cent.	Lead, per Cent.	Fictitious Values by Guillet's Formula.	
					Copper, per Cent.	Zinc, per Cent.
I. and II. .	69·88	30·12	...	...	69·88	30·12
III. .	69·89	29·03	1·08	...	69·15	30·85
IV. .	70·15	28·85	...	1·00	70·15	29·85
V. .	69·90	28·11	...	1·99	69·90	30·10

The "fictitious values" for zinc and copper represent the composition of the puré copper-zinc alloy which would correspond most closely with the actual ternary alloy.

In the first series of experiments, the application of the current was continued for five minutes, the products being analysed immediately afterwards. Alloys I. and II. contain copper and zinc only, I. being unannealed and II. annealed at 800° C. for two hours, whilst III. contains tin and IV. and V. contain lead. The results of these tests are shown in Tables X., XI., and XII. By "precipitate" is meant the flocculent precipitate of basic salts which appears in the electrolyte, and is readily separated from the specimen, whilst "adherent layer" denotes the metallic deposit which was mixed with zinc oxychloride in the cases of Alloys I., II., IV., and V., and with tin oxychloride in the case of Alloy III. This deposit could not be flaked off as with the " β " alloys, this being probably due to the increased amount of basic salts

TABLE X.—*Composition of Precipitate.*

Time, 5 minutes.

Alloy.	Copper, Mgms.	Zinc, Mgms.	Tin, Mgms.	Lead, Mgms.	Total, Mgms.	Copper, per Cent.	Zinc, per Cent.	Tin, per Cent.	Lead, per Cent.
I. {	0·90	0·95	...	...	1·85	48·6	51·4	...	...
	0·95	1·00	...	...	1·95	48·7	51·3	...	...
II. {	1·05	0·95	...	...	2·00	52·5	47·5	...	...
	1·00	0·91	...	...	1·91	52·3	47·7	...	...
III. {	0·30	1·22	none	...	1·52	19·7	80·3	...	...
	0·32	1·08	none	...	1·40	22·8	77·2	...	...
IV. {	1·25	1·26	...	none	2·51	49·7	50·3	...	...
	1·20	1·07	...	none	2·27	52·8	47·2	...	...
V. {	0·60	0·60	...	none	1·20	50·0	50·0	...	...
	0·60	0·57	...	none	1·17	51·3	48·7	...	...

TABLE XI.—*Composition of Adherent Layer.*

Time, 5 minutes.

Alloy.	Copper, Mgms.	Zinc, Mgms.	Tin, Mgms.	Lead, Mgms.	Total, Mgms.	Copper, per Cent.	Zinc, per Cent.	Tin, per Cent.	Lead, per Cent.
I. {	0·425	0·331	...	...	0·756	56·2	43·8	...	...
	0·45	0·315	...	...	0·765	58·8	41·2	...	...
II. {	0·40	0·25	...	...	0·65	61·6	38·4	...	...
	0·375	0·20	...	...	0·575	65·2	34·8	...	...
III. {	2·35	0·13	0·03	...	2·51	93·6	5·2	1·2	...
	2·40	0·31	0·03	...	2·74	87·6	11·3	1·1	...
IV. {	0·80	0·13	...	none	0·93	86·0	14·0	...	...
	0·83	0·20	...	none	1·03	80·6	19·4	...	...
V. {	0·86	0·24	...	none	1·10	78·1	21·9	...	...
	0·86	0·25	...	none	1·11	77·4	22·6	...	...

TABLE XII.—*Total Weight of Corrosion Product.*

(Time, 5 minutes.)

Alloy   I.   .   .   .   2·62 and 2·71 milligrammes.
,,   II.   .   .   .   2·65 ,, 2·49   ,,
,,   III.   .   .   .   4·03 ,, 4·14   ,,
,,   IV.   .   .   .   3·44 ,, 3·30   ,,
,,   V.   .   .   .   2·30 ,, 2·28   ,,

which seemed to be intimately mixed with the coppery deposit
from the surface to its junction with the brass beneath. If
these basic salts were removed by a very dilute solution of
hydrochloric acid (one drop in 30 cubic centimetres of water),
there remained an adherent layer of coppery crystals. This
layer was much more difficult to detach from the brass than
that which was produced in the corrosion of the β-alloys, but,
as in the former experiments, a perfectly sharp boundary
between the brass and the dezincified layer was always present.
In the second series of experiments, 100 cubic centimetres of
the electrolyte were allowed to flow over the surface during a
period of sixty minutes. (Tables XIII., XIV., and XV.)

The total weight of the corrosion product, including both
the precipitate and the adherent layer, is given in Tables XII.
(five-minute tests) and XV. (sixty-minute tests).

Microscopical Observations.

The Alloy I., containing copper and zinc only, had a very
distinctly cored structure when examined in the cast condition,
the appearance under the microscope being characteristic of
an α-solid solution in a state of imperfect equilibrium. An-
nealing for two hours at 800° rendered the alloy perfectly
homogeneous. A specimen was also examined in this state,
and appears in the tables as Alloy II. Alloy III., containing
tin (1·08 per cent.), was also heterogeneous in the cast condi-
tion, showing distinct segregation of the copper-tin constituent
at the boundaries of the crystals. This constituent disappeared
on annealing, and this and the remaining alloys were only
employed for the corrosion tests in the annealed condition.
Alloy IV. did not become completely homogeneous on anneal-
ing, but small isolated areas of lead remained undissolved
here and there, whilst Alloy V., with twice the quantity of
lead, showed well-defined bands of segregated lead at the
boundaries of many of the crystals.

The behaviour of the alloys on corrosion was characteristic,
and strikingly different from that of the β-alloys. This was
specially noticeable in regard to the film of copper left after
dezincification. This was always intimately mixed with basic

Whyte and Desch :

TABLE XIII.—*Composition of Precipitate.*

Time, 60 minutes.

Alloy.	Copper, Mgms.	Zinc, Mgms.	Tin, Mgms.	Lead, Mgms.	Total. Mgms.	Copper, per Cent.	Zinc, per Cent.	Tin, per Cent.	Lead, per Cent.
I. {	8·00	5·67	...	...	13·67	58·5	41·5	...	...
	8·00	5·60	...	...	13·60	58·8	41·2	...	...
II. {	8·50	5·35	...	...	13·85	61·3	38·7	...	...
	8·40	5·30	...	...	13·70	61·3	38·7	...	...
III. {	1·20	7·18	trace	...	8·38	14·3	85·7	...	...
	1·20	7·68	trace	...	8·88	13·5	86·5	...	...
IV. {	6·00	4·54	...	none	10·54	56·9	43·1	...	...
	6·20	4·60	...	none	10·80	57·4	42·6	...	...
V. {	5·00	4·09	...	none	9·09	55·0	45·0	...	...
	5·04	4·09	...	none	9·13	55·2	44·8	...	...

TABLE XIV.—*Composition of Adherent Layer.*

Time, 60 minutes.

Alloy.	Copper, Mgms.	Zinc, Mgms.	Tin, Mgms.	Lead, Mgms.	Total, Mgms.	Copper, per Cent.	Zinc, per Cent.	Tin per Cent.	Lead, per Cent.
I. {	6·55	1·73	...	...	8·28	79·1	20·9	...	...
	6·45	1·60	...	...	8·05	80·1	19·9	...	...
II. {	5·45	1·57	...	...	7·02	77·6	22·4	...	...
	5·35	1·58	...	...	6·93	77·2	22·8	...	...
III. {	13·00	1·41	0·165	...	14·57	89·2	9·7	1·1	...
	13·00	1·58	0·165	...	14·74	88·1	10·8	1·1	...
IV. {	7·50	1·73	...	0·09	9·32	80·5	18·54	...	0·96
	7·25	1·35	...	0·09	8·69	83·5	15·5	...	1·0
V. {	4·25	1·25	...	0·11	5·61	75·7	22·3	...	2·0
	4·00	0·95	...	0·11	5·06	79·1	18·8	...	2·1

TABLE XV.—*Total Weight of Corrosion Product.*

(Time, 60 minutes.)

Alloy I. . . . 21·95 and 21·65 milligrammes.
  ,, II. . . . 20·87 ,, 20·63 ,,
  ,, III. . . . 22·95 ,, 23·62 ,,
  ,, IV. . . . 19·86 ,, 19·49 ,,
  ,, V. . . . 14·75 ,, 14·19 ,,

PLATE XVI
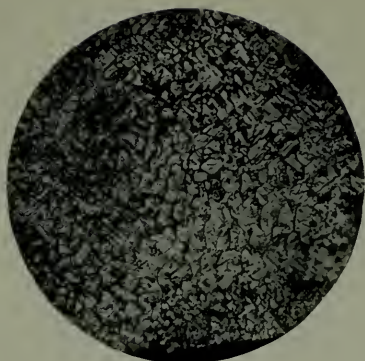
FIG. 1.—Alloy I. 1-hour Test.
Etch Figures. Magnified 200 diameters.
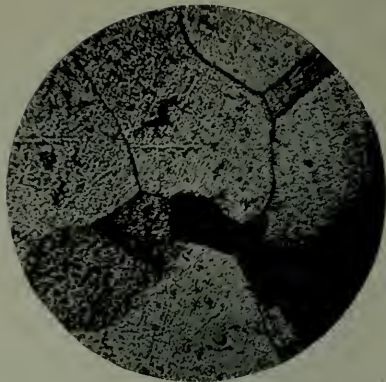
FIG. 2.—Alloy III. Coppery layer removed.
Magnified 45 diameters.
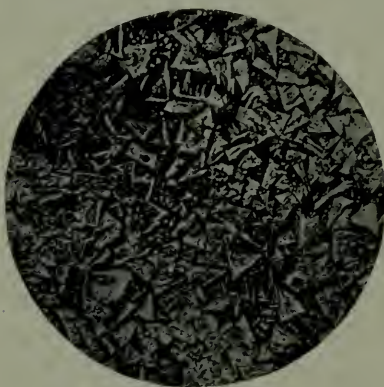
FIG. 3.—Alloy V.
Etch Figures. Magnified 200 diameters.

Fusible Metal.

Copper

Brass
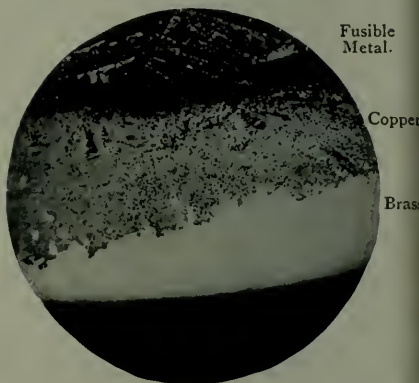
FIG. 4.—Section of Corroded Condenser
Tube. Magnified 200 diameters.
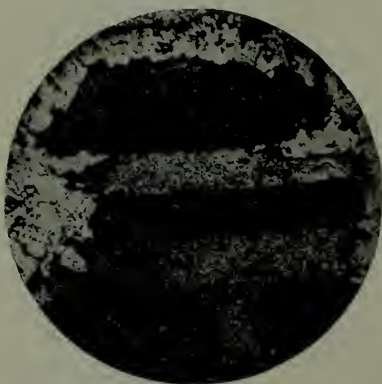
FIG. 5.—Corrosion along Boundaries and
Twinning Planes.
Magnified 160 diameters.

Brass.

Copper

Fusible Metal.

FIG. 6.—Artificial Corrosion of Condenser
Tube. Magnified 30 diameters.

salts, which adhered very firmly, and, having a dull surface with low reflecting power, made it difficult to obtain satisfactory photographs. Momentary immersion in very dilute hydrochloric acid removed the greater part of the oxychloride, exposing the coppery layer, which was invariably made up of small crystals, mainly exhibiting octahedral angles. In the long-period tests etch-figures were conspicuously developed, cubic forms being frequently observed. Plate XVI. Fig. 1, taken from Alloy I., shows this effect, the cubic angles being well seen surrounding a rather deep etching-pit on the left.

Fig. 2, taken from Alloy III., shows the general appearance of the surface after detaching the film of copper. The crystal boundaries have been revealed by the corrosion, and the difference of orientation in neighbouring grains is perceptible, but is somewhat less conspicuous than in the β-alloys under similar conditions. The black area in this photograph represents a firmly adherent layer of oxychlorides, covering one or more crystal grains. The cored structure of the unannealed specimen, Alloy I., was strongly developed during corrosion, finally leaving ridges in high relief, whilst the annealed alloys corroded very uniformly.

The effect of lead was remarkable. On clearing off the adherent layer from Alloys IV. and V., each isolated mass of lead was seen to be surrounded by a ring of copper. Octahedral etch figures were strongly developed, as is shown in Fig. 3.

The Relation between Natural and Electrically Stimulated Corrosion.

An opportunity of comparing the effects produced by the application of an external electromotive force to an α-brass in contact with salt solution with those observed in the corrosion of a similar brass under conditions of service was afforded by the examination of some condenser tubes. These tubes had been taken from a vessel on the Manchester Ship Canal, and exhibited in parts, especially near to the inlet end, very considerable dezincification, extending over the whole internal surface of the tube, but penetrating completely through the tube along a horizontal strip, occupying about one quarter of

Q

the circumference, and forming the bottom of the tube. Along
this strip the zinc had been completely removed, a transverse
section showing nothing but somewhat spongy copper. The
upper part of the tube, in the same section of its length, was
dezincified to a small depth, becoming deeper in the lower part,
and merging into the completely dezincified area.

A transverse section of one of the typically corroded portions
was prepared, the tube being previously filled with fusible
metal, in order to prevent any cracking or separation of the
coppery layer during sawing. Fig. 4 is a section of a part of
the tube where dezincification has extended half way through
the thickness of the metal. The section has been slightly
heat-tinted, so as to darken the copper, leaving the uncorroded
brass quite bright. The boundary between the two is irregular,
but perfectly sharp. This characteristic feature of dezincifica-
tion was also observed in the β-alloys described in the former
paper.

Further insight into the mechanism of the process is afforded
by an examination under a higher magnification, after etching
with ammonia. Fig. 5 shows an area at the boundary of the
corroded and the unchanged portions after being treated in
this way. The light constituent visible at the circumference
of the circle is porous copper, whilst the greater part of the
area is α-brass. Dezincification has proceeded, as usual, along
the boundary of the crystal grain. As usual in annealed
brasses, the α-constituent shows repeated twinning, and it is
interesting to observe that dezincification has invaded the
mass of the crystal grain along a twinning plane. This be-
haviour is characteristic of the α-brasses, and is observed
throughout in this and similar specimens, whether corroded
naturally or under the influence of an applied electromotive
force. It indicates an electro-chemical difference at a twinning
plane, an effect which, although not often observed, is to be
expected on theoretical grounds.

The attempt was next made to reproduce this corroded
structure by using an applied electromotive force. A clean,
uncorroded piece of the same tube was taken, cut to a length
of 2 centimetres, and formed into a cell, containing the same
electrolyte (5 per cent. sodium chloride solution) as that used

throughout the experiments. The tube was the anode and a platinum wire was the cathode. After remaining connected with the cells for twenty-four hours the section of tube was washed, filled with fusible metal, sawn through, and polished. De-zincification was found to have taken place to a considerable depth. The effect is shown in Fig. 6, the structure having been developed by heat-tinting. As before, the boundary between spongy copper and brass is a very sharp one, and is found, on examination under a higher magnification, to follow the outline of the crystal grains, penetrating into them along the twinning planes. There is thus complete identity between the corroded structure which was produced under working conditions in contact with the water of the Manchester Ship Canal and that obtained artificially, using salt solution and an external electromotive force.

The composition of the condenser tube was somewhat unusual, the proportion of zinc being considerably below that of a normal 70 : 30 brass. Several concordant analyses gave as the composition :—

							Per Cent.
Copper	.	.	.	.	.	.	72·72
Zinc	.	.	.	.	.	.	27·04
Iron	.	.	.	.	.	.	0·15
Lead	.	.	.	.	.	.	0·09
							100·00

There is no reason to suppose that this difference in the percentage of zinc makes any appreciable difference in the process of corrosion.

DISCUSSION OF RESULTS.

The total corrosion of the α-alloys is, as might be expected, much less than that of the β-alloys under the same conditions. A relatively much larger proportion of copper is also removed in solution, that is, there is less preferential removal of zinc than in the case of the β-alloys. This also is in accordance with expectations, the α-solid solution having less tendency to lose zinc than the more concentrated β-solution.

There is very little difference between the resisting powers of the unannealed and annealed alloys of copper and zinc (I.

and II.), but such small differences as occur are uniformly in the direction of lessened corrosion after annealing. Of the remaining alloys, the greatest amount of corrosion is given by that containing tin, and the least by that containing 2 per cent. of lead.

It must be repeated that this method determines only the initial stages of the process of corrosion, and the results must be interpreted from this point of view. The physical character of the process is as important as its chemical nature, since the physical properties of the deposit formed on the surface of the metal determine whether subsequent corrosion will proceed with constant or accelerated velocity, or will be gradually brought to a standstill.

Taking Alloy II. as a standard of comparison, it is seen that Alloy I., the structure of which is less homogeneous owing to the presence of cores, corrodes to a slightly greater extent, the removal of zinc taking place principally at the periphery of the crystallites. Dezincification proceeds here to a greater extent, but there is no important difference in the physical properties of the adherent layer in the two cases.

Alloy III., containing tin, is corroded much more rapidly at first than Alloy II. In the five-minute tests, this difference is very marked, but it becomes less in the sixty-minute tests, and there is little doubt that it would disappear and even be reversed in tests continued over longer periods. This is due to the formation of a remarkably tough layer of basic salts. Dezincification proceeds far, but the coppery layer, instead of being easily detachable, is firmly cemented to a compact mass by basic salts, the tin being retained in this deposit. Such a layer must offer a considerable obstacle to further corrosion. This effect was also observed in the experiments with β-alloys.

Alloy IV., containing 1 per cent. of lead, also shows dezincification, but the adherent layer, unlike that of the tin alloy, is loose and open in texture. It is therefore not surprising that the total corrosion is not lessened appreciably; in fact, the five-minute tests show an increase.

Alloy V., containing 2 per cent. of lead, is dezincified locally, the areas of free lead becoming surrounded by a zone of copper, which gradually extends over the entire surface as

the process is continued. The coppery layer is very firmly adherent. In its upper portions it is cemented by basic salts, but a layer of copper, containing comparatively little zinc, intervenes between this varnish-like layer and the unchanged metal. The total corrosion is less than that of any of the other alloys, and the advantage becomes more pronounced as the time of testing is extended, being greater in the sixty-minute than in the five-minute tests.

The experiments have confirmed the authors in their opinion that there is no essential difference between the processes of electrically stimulated and natural corrosion, and that consequently the method that they have described may be employed for the purpose of determining the probable order of resistance of alloys to corrosion. The results now presented are in good agreement with the conclusions of Dr. Bengough's report as to the suitability of different alloys of the a-series. It is next proposed to examine the influence of other added metals on the a-alloys, and also the behaviour of the a-β- or Muntz metal alloys.

DISCUSSION.

Dr. G. D. BENGOUGH, M.A. (Liverpool), said that he need hardly say he had taken the greatest possible interest in the paper which had been presented to the Institute by Mr. Whyte and Dr. Desch. He was very glad indeed to think that in a great many particulars the conclusions to which they had arrived were the same as those which he himself had come to, working in rather a different way. One of the most interesting points that the authors had brought forward was that of the effect of tin. He (the speaker) had never been able really to picture in his mind exactly how the tin exerted its particular action. The authors' suggestion of a varnish occurring all over the metal was very interesting indeed, because it really did look like that, even when ordinary chemical corrosion was being dealt with, and not the electro-chemical corrosion which they mentioned. But he would inquire of what the varnish consisted? There was a sort of glazed appearance on the tubes, but no definite layer of basic salts extending all over the tubes could be seen. They had a sort of glazed appearance, and he supposed that the authors had imagined that that was a very thin transparent layer.

Dr. DESCH said the corrosion they had mentioned was much more rapid, and the layer in the case of their experiments was distinctly opaque.

Dr. BENGOUGH, continuing, said in his case he obtained only a curious glazed look over the tube when it contained tin.

The effect of lead was also most interesting. He believed Mr. Brühl, in his paper on "The Corrosion of Brass," * was the first to suggest that 1 per cent. of lead did no harm, and that was confirmed by Sir Gerard Muntz.

With regard to the question of dezincification, he quite saw the authors' point of view, and he was not bigoted in the view which his colleague and himself had put forward in their Report; and of course he realized that they (the authors) had been in a much better position to study that particular point than he himself had been with his very slow corrosion. Therefore, he was inclined to give very great weight to what the authors said about dezincification, and was ready to agree that he might have given the more correct explanation. As he had said, his own corrosion had been very slow, and there were no means of differentiating between dezincification and subsequent oxidation; they were both very slow—very much slower than the authors'. Therefore, it was quite possible that dezincification did really proceed first, and that oxidation was obtained subsequently. The authors were in a so much better position to judge of that than either his (the speaker's) colleague or himself that he was quite willing to accept their opinion on that point.

The authors had brought out a most interesting fact, namely, that dezincification was obtained round the lead crystals. He (the speaker) had not observed that in any of his experiments. It evidently indicated

* *Journal of the Institute of Metals*, No. 2, 1911, vol. vi. p. 302.

electrolytic action going on, and it seemed very remarkable in view of that, that the lead should protect; and he would like Dr. Desch to give a little more information upon that point, because it was very difficult to see how those two observations could be harmonized.

He had not yet studied the microstructure of lead-bearing tubes, because so far he had not succeeded in dezincifying them in the way he had the other tubes. On Plate XVI. were given some most remarkable photographs. No. 5 was one of the most interesting he had seen—the penetration of the dezincification along the planes of twinning. Since the photograph had been published he (the speaker) had examined some chemically corroded specimens, and had seen the same thing; but he had not noticed it before seeing the authors' photograph—it was not so evident in his specimens. He thought it was a most important fact in connection with all corrosion phenomena. The credit of discovering it belonged entirely to the authors, because he (the speaker) had not seen it until he had received the microphotographs. The authors suggested that mechanical protection was the secret of the success of both lead and tin. His (the speaker's) colleague and himself came to the conclusion that physical causes were also the real crux of the question in connection with the dezincification of condenser tubes in spots; and up to the present time they had not paid sufficient attention to the minute physical differences which occurred along condenser tubes. They now thought it was minute differences in physical conditions which determined the particular spots at which dezincification of ordinary condenser tubes would begin. He did not want to enlarge on that point, because the work was still progressing; but it did seem to agree with the authors' contention that the mechanical and physical effects were equally as important as chemical effects in the very difficult phenomenon of corrosion. The authors had indicated that they were now examining alloys of the Muntz metal type which contained the two phases α and β. In his (the speaker's) experiments he had had Muntz metal tubes in the Corrosion Committee's plant for some time, and they had become dezincified in a most extraordinary way. Dezincification had penetrated nine-tenths of the way through the tubes in nine months; and as that alloy had been rejected as being unsuitable for condenser tubes, and as a large number of dezincified spots had been obtained, he had been studying the microstructure of it; and he would like to say one or two words in connection with the point. He had in his hand colour photographs prepared in the following way. He had taken the Muntz metal, had etched it with ammonia, and then left it for three days to oxidize in the air. It was simply a modification of Dr. Stead's heat-tinting process, and it tinted the copper a much finer red for photographic purposes. If that was done some very interesting results were obtained. The ammonia etched the β dark. Where the Muntz metal had been in contact with sea water the β crystals were entirely dezincified, and they then existed in the alloy as pseudomorphs in copper after β. If the colour photographs were held in the right position, some of the β crystals could be seen partially dezincified—that is, half of each crystal was dezincified and half retained its zinc. He imagined that this indicated twin β-crystals,

although they were so strained that the microstructure could not very well be made out.

There was also another very interesting thing shown by the photographs, namely, that round the copper all the α was stained dark, because it was electro-positive to the copper; whereas away from the copper the β was dark and the α remained light. He thought those points were interesting in connection with the work which the authors were at present doing on Muntz metal; they showed very well the electro-chemical relations of the copper with the α and the β. He would pass the slides round to the members.

Mr. J. DEWRANCE (London) inquired whether the authors had tried any other alloys instead of those containing a large percentage of zinc in order to avoid corrosion. Many years ago his firm used to employ brass for pressure gauge tubes, and had had experience of the troubles in corrosion that came out in discussions on the corrosion of condenser tubes. The remedy his firm found to be to use copper containing 5 per cent. of tin. That material was very much stronger; it was quite sufficiently elastic for the purpose, and was extremely free from the troubles of corrosion, which occurred with the alloys containing large percentages of zinc. Zinc was a chemically active metal, likely to corrode with all sorts of electrolytes and impurities in water; whereas copper and tin were metals which were very much less chemically active.

Professor W. E. OAKDEN (London) said that he had not read the paper, but he gathered from one remark which had fallen from Dr. Desch, that the authors had arrived at the conclusion that the cause of corrosion was more mechanical than chemical. Considering that the authors' experiments were, really speaking, electrolytic and partly chemical, he would like Dr. Desch to explain on what grounds they (the authors) had arrived at the conclusion that the corrosion was almost purely mechanical rather than electrolytic or chemical.

Dr. WALTER ROSENHAIN, F.R.S. (Member of Council), said that he had discussed the point raised by the paper when the Report of the Corrosion Committee had been presented at Ghent, but he felt obliged to raise it again that afternoon. He did not think it had ever yet been proved —certainly he did not consider that the authors had proved it in their paper—that corrosion was necessarily dezincification in condenser tubes or in brass; in fact, Dr. Desch's own statement, that in certain circumstances the film of copper was oxidized as fast as it was formed, was a contradiction of the very statement he made. If the film of copper was oxidized as fast as it was formed, then there was no preferential oxidation of the zinc or solution of the zinc. He (the speaker) considered that uniform solution was really what did happen in a great many cases. It seemed quite impossible to suppose that there was dezincification going locally right through the tube, leaving no sign or symptom of dezincification anywhere else. If such a process had been at work, he thought the mere theory of probability would make one realize that if there were

half a dozen pits in a tube which had gone right through, and yet no dezincification was found either surrounding these pits or anywhere else, that it was fair to conclude that there had been no dezincification in the ordinary sense of the word at work in that particular case. Of course, a good deal of dezincification did occur, and very likely it was the most important cause of corrosion ; but there were certain cases—and it happened to have been his fortune to have come across rather a majority of those—in which there had been no sign whatever of dezincification, even although a most careful search was made for it. He wanted a good deal stronger evidence than that which had been brought forward to make him believe that it was always dezincification which occurred. He considered the authors' suggested test—the accelerated test—was valuable, as all acceleration tests were, but it had its limitations, and one had to be very careful in accepting the results. He thought it would have to be used with caution—possibly with a little more caution than the authors had indicated in their paper. The authors had shown that where dezincification occurred in a natural case of corrosion the result looked very like that of the electrolytically stimulated dezincification which they had obtained in their test. It did not follow that in other cases there was the same similarity or correspondence. It was very likely a valuable and useful test in many cases, but he did not think it would give a clue or to all forms of corrosion which were likely to occur.

He had been very much interested in Mr. Whyte's and Dr. Desch's observation with regard to dezincification following along the boundaries of twin laminæ. He thought the difference of the electric-potential between the twin laminæ and the crystal was shown experimentally by the mere fact that the twins could be seen in the microstructure. If it were not for that electro-chemical difference between the twins, they would not etch out. Therefore the mere fact that a twin boundary could be seen as a line under the microscope showed there was that electro-chemical difference, and consequently it followed that such a process as dezincification should be propagated, not strictly speaking along that line, but near it. It was not confined to the actual boundary, but occurred in the material near the boundary ; it was merely something which was stimulated, and progressed more rapidly where there were local electro-chemical differences.

Dr. DESCH, in reply, said in the first place he did not desire to have the paper referred to at all as his paper, because to Mr. Whyte was due a full share of the conclusions, as well as most of the experimental work.

He was glad to find that Dr. Bengough, with his wide experience of corrosion, was inclined to look upon their explanation as a reasonable one. Dealing with one or two of the points Dr. Bengough had mentioned, the effect of lead certainly did at first seem to be to stimulate corrosion. Dezincification started just round the lead particles, and that had been one of the things which had led them to say that electro-chemical conditions were comparatively unimportant as compared with physical conditions. Somehow or other, when that layer of spongy copper had been formed round the lead it became plugged up with a basic salt.

With lead present the salt was not the same as with tin present. It was a white layer, not a green layer containing copper salts, but it was quite tough; and it had been found that after a little time that tough layer was very difficult to detach. With only 1 per cent of lead, the layer was easily detached. In the absence of lead and tin it was quite easily detached; and they had attributed the protective effect to the formation of the varnish.

With regard to the method of developing the structure, most of the specimens were heat tinted, but etching was sometimes necessary. Photograph No. 3 showed a remarkably loose structure in the metal after removal of zinc.

Mr. Dewrance had asked if they had examined other alloys than the copper-zinc. They had not done so; so far they had only examined copper-zinc alloys, with the addition of various third metals. It was hoped to extend the investigation to other alloys as well, but as Mr. Whyte was just leaving him, he was not quite sure how far it would be possible to carry on the research.

Professor Oakden had misunderstood what he had said. Professor Oakden seemed to think he had spoken of the cause of corrosion being mechanical rather than chemical, whereas what he really had said was that he thought the influence of certain metals in checking corrosion was mechanical rather than chemical.

Dr. Rosenhain was somewhat sceptical, and he (Dr. Desch) admitted that the evidence they had to bring forward on those points was not conclusive. His colleague and himself had been led to certain conclusions, but they did not wish at all to suggest that they had proved their case entirely. When he said that the layer of copper was oxidized as fast as it was formed in natural corrosion, that was not strictly accurate; he meant nearly as fast—that as soon as a layer of copper had been formed it was soon converted into oxide. He was still inclined to believe that the first process was always the formation of a layer of metallic copper. He had not had the opportunity of examining tubes showing the type of corrosion to which Dr. Rosenhain had referred, where the material had been thinned away, and there was no layer of copper left behind, but even in that case it was quite possible that so spongy a layer might be removed, and he (the speaker) would not be prepared even at the present time to admit that the process was essentially different even in that case.

With regard to the twin lamellæ, when they (the authors) said that the corrosion proceeded along the boundaries between twin lamellæ, they did not mean that it proceeded along one fine line, but that where there were several alternating lamellæ, certain of those were corroded more rapidly than the others. It would be seen in photograph 5 that the formation of copper proceeded along one of those parallel bands. The fact that one could reveal the twin structure by etching hardly seemed to him to prove electro-chemical differences. In neighbouring lamellæ the orientation of the particles was different; one appeared dark and the other light, but that did not mean that the dark one was more etched than the other, because on rotating the specimen the dark one became light. There was a difference of orientation.

Dr. ROSENHAIN said there was also a difference of level—one was above the other.

Dr. DESCH said he would have said they were inclined like the roof of a house.

Dr. ROSENHAIN said there were light boundaries between them.

Dr. DESCH said he must confess he had not examined the specimens with sufficient care, and had probably overlooked the point.

THE QUANTITATIVE EFFECT OF RAPID COOLING UPON THE CONSTITUTION OF BINARY ALLOYS.*

PART II.

By G. H. GULLIVER, B.Sc., F.R.S.E., A.M.I.Mech.E.

I. Calculation of the Constitution of Quickly Cooled Alloys when the Curvature of Solidus and Liquidus is Considerable.

In a former paper on this subject † it was shown that calculations of the proportion of liquid or of eutectic in quickly cooled alloys, based on the assumption of a straight liquidus and solidus, are not seriously erroneous if these lines have a moderate degree of curvature; this is particularly the case when, as with the lead-tin liquidus, the curve oscillates about the straight line. But sometimes the degree of curvature is considerable, and the liquidus or solidus lies wholly on one side of the straight line drawn from the freezing-point of the pure metal to the eutectic point, or to the saturation point, as the case may be. Now the proportion of solid formed during a small fall of temperature depends upon the angles of slope of the solidus and liquidus, and upon the horizontal distance between these lines in the region considered. Hence if the liquidus is wholly convex and the solidus is wholly concave upwards the proportion of liquid in quickly cooled alloys is greater than for a liquidus and solidus assumed straight; if the liquidus is concave and the solidus is convex upwards the proportion of liquid is less; if both are curved in the same direction the effect depends upon the mean inclination of the lines and their degree of curvature in a given region.

A suitable method of calculation, when the curvature is such that it must be allowed for, has been already indicated. A still better way is to divide the portion of the equilibrium diagram under consideration into a number of parts by horizontal lines, between each adjacent pair of which the solidus and liquidus differ but slightly from straight lines, and
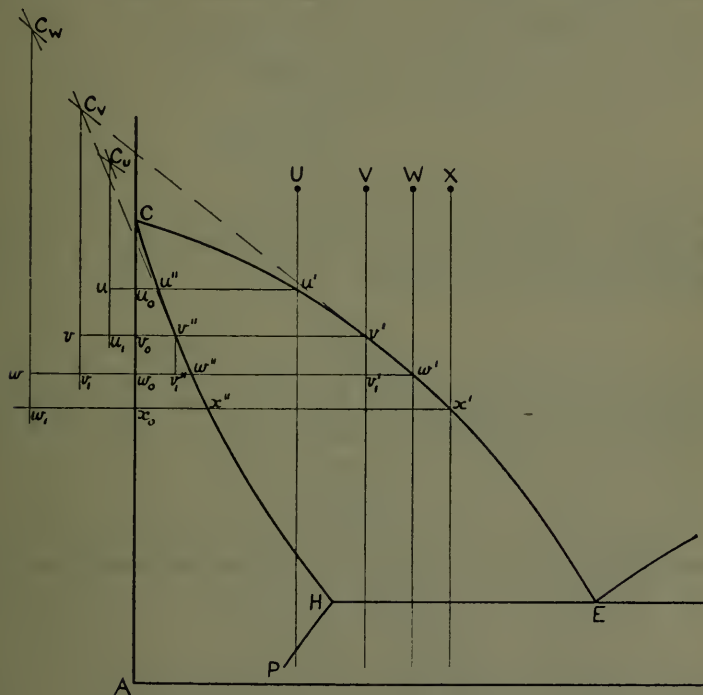
FIG. 1.—Part of equilibrium diagram, illustrating the method employed for calculating the proportion of liquid in rapidly cooled alloys when the curvature of liquidus and solidus is considerable.

then to make use of the result for an indefinitely rapid rate of cooling for each part; there is no necessity that the parts should be equal; in fact their size is better regulated by the degree of curvature of liquidus and solidus. In Fig. 1 the compositions of the alloys U, V, W, and X are supposed to be chosen so that the sections $u'v'$, $v'w'$, $w'x'$ of the liquidus and the sections $u''v''$, $v''w''$, $w''x''$ of the solidus do not

deviate from straight lines by more than some arbitrarily chosen small quantity. The lines $v'u'$ and $v''u''$ are produced to intersect in C_U, $w'v'$, and $w''v''$ to meet in C_V, and so on; through C_U, C_V, &c., vertical lines are drawn to meet $u'u''$ in u, $v'v''$ in v, &c., respectively.

The expressions (7) and (7a) * were previously kept in the form most convenient for numerical calculations. They can be more briefly written,

$$\text{Proportion of liquid (rapid cooling)} = \left(\frac{y_0}{y_r}\right)^{\frac{\tan\theta}{\tan\theta - \tan\phi}}$$

$$= \left(\frac{X}{X_E}\right)^{\frac{X_E}{X_E - X_S}} \quad . \quad . \quad . \quad . \quad (7b)$$

the latter form being the more convenient in use. The proportion of liquid in the rapidly cooled alloy U at the temperature of vv' is therefore

$$\left(\frac{u\,u'}{u_1 v'}\right)^{\frac{u_1 v'}{v'' v'}}$$

Similarly, the proportion of liquid in the rapidly cooled alloy V at the temperature of ww' is

$$\left(\frac{vv'}{v_1 w'}\right)^{\frac{v_1 w'}{w'' w'}}$$

Hence the proportion of liquid in U at the temperature ww' is

$$\left(\frac{u\,u'}{u_1 v'}\right)^{\frac{u_1 v'}{v'' v'}} \cdot \left(\frac{vv'}{v_1 w'}\right)^{\frac{v_1 w'}{w'' w'}}$$

The proportion of liquid in U at the temperature xx' is

$$\left(\frac{u\,u'}{u_1 v'}\right)^{\frac{u_1 v'}{v'' v'}} \cdot \left(\frac{vv'}{v_1 w'}\right)^{\frac{v_1 w'}{w'' w'}} \cdot \left(\frac{ww'}{w_1 x'}\right)^{\frac{w_1 x'}{x'' x'}}$$

and so on. The simplest method of procedure is to determine numerically the proportion of liquid in each quickly cooled alloy at the freezing temperature of the chosen alloy next below it, and to perform the necessary multiplication afterwards. It is therefore most convenient to begin with the chosen alloy which has the lowest freezing-point. This

method, when applied to the lead-rich alloys of the lead-tin series, shows that the effect of curvature of the liquidus in this case is negligible, a conclusion already reached by a rougher method. In Fig. 10 the open circles indicate points plotted for an assumed straight liquidus, corresponding with the figures given in the fourth column of Table I.,* and the black dots show the results obtained by dividing the true liquidus into ten portions and using the method just explained; this portion of Fig. 10 is similar to Fig. 9 † of the previous paper, but illustrates an indefinitely rapid rate of cooling instead of a moderately slow one.

The method is applied below to the more useful alloys of the copper-tin and the copper-zinc series, for which the results are of some practical importance. The fact that in these alloys the various branches of the liquidus end at transition points, instead of at eutectic points, alters nothing in the method of calculation.

Apart from errors in the experimental determination of the equilibrium diagram, there are others introduced into the calculations by insufficiently close approximation of the short straight sections to the true curves, and by defective draughtsmanship; these, while preventing the attainment of mathematical accuracy, may be reduced by ordinary care and trouble to quantities altogether negligible in practice. The intersections of the chosen portions of the solidus and liquidus are not infrequently bad ones, that is, the lines are inclined at only a small angle to each other, or the intersection may even lie off the drawing paper; the horizontal positions of these points are then best checked by calculation. Thus, if C_V is the intersection of $w'v'$ with $w''v''$, and $C_V v$ is drawn vertically, then by simple geometry

$$\frac{v_1'w'}{v_1''w''} = \frac{vv'}{vv''} = \frac{vv'' + v''v'}{vv''}$$

or

$$vv'' = \frac{v_1''w'' \cdot v''v'}{v_1'w' - v_1''w''}$$

And $vv_0 = vv'' - v_0v''$ is the distance of the vertical line $C_V v$

* *Loc. cit.*, p. 138.   † *Loc. cit.*, p. 150.

from CA. The distances $v_1''w''$, $v''v'$, $v_1'w'$, and v_0v'' are all obtained from the diagram.

When the liquidus and solidus are curved it does not always happen that corresponding sections of these lines are convergent upwards; they sometimes converge downwards, and occasionally become sensibly parallel for a short distance. It is necessary therefore to inquire what corresponding change there is in the expression which gives the quantity of liquid present in a rapidly cooled alloy.
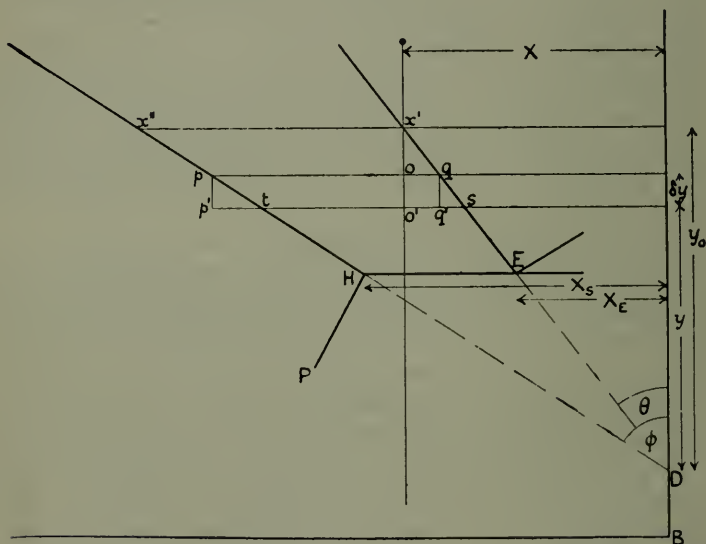
Fig. 2.—Part of equilibrium diagram, with solidus and liquidus convergent downwards, and notation suitable for infinitesimal steps.

When the liquidus and solidus converge downwards the conditions are as represented in Fig. 2, which should be compared with Fig. 4 * in the previous paper. Here m and n, θ and ϕ, are measured as before, but y and y_0 are measured upwards instead of downwards, and X, X_S, and X_E are measured from the right instead of from the left. Obviously,

$$n > m, \ y_0 > y, \ \tan \phi > \tan \theta, \ X_S > X_E, \ X > X_E.$$

* *Loc. cit.*, p. 132.

The quantity of liquid present in a rapidly cooled alloy is therefore more conveniently written in this case as

$$\left(\frac{y_r}{y_0}\right)^{\frac{\tan\theta}{\tan\phi - \tan\theta}} \quad \text{or} \quad \left(\frac{X_E}{X}\right)^{\frac{X_E}{X_S - X_E}} \quad \ldots \ldots \quad (7c)$$

When the liquidus and solidus are parallel, as in Fig. 3,
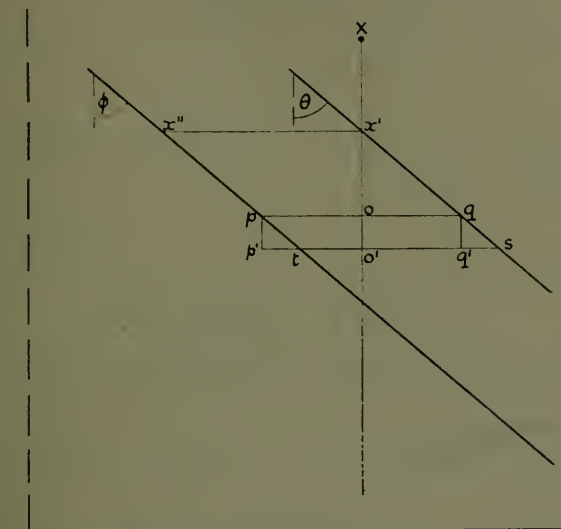
FIG. 3.—Part of equilibrium diagram, with solidus and liquidus parallel.

$m = n$, and a is the same for all alloys. Hence the expression (2) * becomes,

$$\text{Liquid} = \frac{a-m}{a} \cdot \frac{a-m}{a} \cdot \quad \ldots \quad \text{to } r \text{ factors}$$

$$= \left(1 - \frac{m}{a}\right)^r$$

The limiting value of this expression, when r is large and m is small, is

$$\epsilon^{-\frac{rm}{a}} = \epsilon^{-\frac{M}{a}} \quad \ldots \ldots \ldots \ldots \quad (7d)$$

where M is written for rm, and is equal to the difference between the composition of the original alloy and that of

* *Loc. cit.*, p. 128.

R

the liquid portion of it at the given temperature; in Fig. 3, for the alloy X, at the temperature pq, $M = oq$, and $a = x''x'$. The same result may be obtained from the expression ($7b$). For, when liquidus and solidus are parallel, $X_E = X + M$, and $X_E - X_S = a$; X is indefinitely large and M is finite. Therefore,

$$\left(\frac{X_E}{X}\right)^{-\frac{X_E}{X_E - X_S}} = \left(\frac{X + M}{X}\right)^{-\frac{X + M}{a}}$$

$$= \left(1 + \frac{M}{X}\right)^{-\frac{X}{a}}$$

$$= \epsilon^{-\frac{M}{X} \cdot \frac{X}{a}} \qquad \text{in the limit,}$$

$$= \epsilon^{-\frac{M}{a}}$$

II. THE COPPER-TIN ALLOYS.

Fig. 4 shows the portion of the equilibrium diagram to be
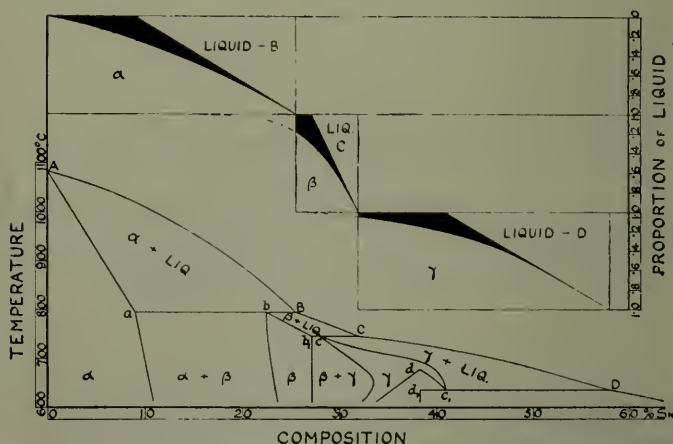
FIG. 4.—Part of equilibrium diagram for copper-tin alloys, and diagrams indicating the increase in the proportion of liquid caused by rapidly cooling alloys which reject α-, β-, and γ-crystals respectively.

dealt with, drawn from the experimental results of Roberts-Austen and Stansfield, of Heycock and Neville, and of

Shepherd and Blough.* The percentages of tin which correspond with the various critical points of the diagram are,

$$a = 9 \cdot 0 ; \qquad b = 22 \cdot 5 ; \qquad B = 25 \cdot 5 ;$$
$$b_1 = 27 \cdot 2 ; \qquad c = 28 \cdot 0 ; \qquad C = 31 \cdot 9 ;$$
$$d_1 = 38 \cdot 4 ; \qquad c_1 = 41 \cdot 0 ; \qquad D = 58 \cdot 0 ;$$

respectively. These are believed to be as nearly correct as they can be fixed at present; future experiments may show small errors in some or all of these points. The liquidus curves AB, BC, CD have been determined with very considerable accuracy, but the solidus curves Aa, bb_1, and cc_1 require further investigation in order to determine their exact forms. Any correction of the equilibrium diagram will necessitate, of course, a corresponding correction of the results of this paragraph.

In alloys containing less than 25·5 per cent. of tin, the copper-rich crystals, designated a, crystallize from the liquid. The branch AB of the liquidus is of fairly uniform curvature, and for the purpose of calculating the constitution of rapidly cooled alloys the curve has been divided into eight equal parts, giving seven alloys which contain 3·5, 6·95, 10·4, 13·65, 16·8, 19·85, and 22·75 per cent. of tin respectively. The proportion of liquid remaining in each of these alloys at the temperature aB has been calculated by the method outlined in the preceding paragraph, and the results are plotted in the upper left-hand corner of Fig. 4. The ordinates of the straight line drawn from 9 to 25·5 per cent. of tin represent the constitution of alloys when in equilibrium; the ordinates of the black area represent the excess of liquid occasioned by very rapid cooling, exactly as in Fig. 5 † of the previous paper. By taking a larger number of alloys than the seven chosen, a slight correction would be made in the calculated proportion of liquid for rapid cooling, but excessive subdivision of the liquidus merely entails laborious calculations for the sake of an unnecessary and often spurious accuracy.

* Roberts-Austen and Stansfield, *Proceedings of the Institution of Mechanical Engineers*, 1895, p. 269 ; 1897, p. 67. Heycock and Neville, *Proceedings of the Royal Society*, 1901, vol. lxix. p. 320 ; *Philosophical Transactions*, 1897, vol. clxxxix. A, p. 25 ; 1904, vol. ccii. A, p. 1. Shepherd and Blough, *Journal of Physical Chemistry*, 1906, vol. x. p. 630.

† *Loc. cit.*, p. 135.

For alloys containing 25·5 to 31·9 per cent. of tin, in which the primary crystallization consists of the β-solution, the liquidus BC is so nearly straight that it has been assumed accurately so, and the proportion of liquid has been calculated in the same manner as was first employed for the lead-tin alloys, the proportionate error being probably of the same order as in that case. The straight lines CB and b_1b meet at 14·2 per cent. of tin, and the curve which represents the
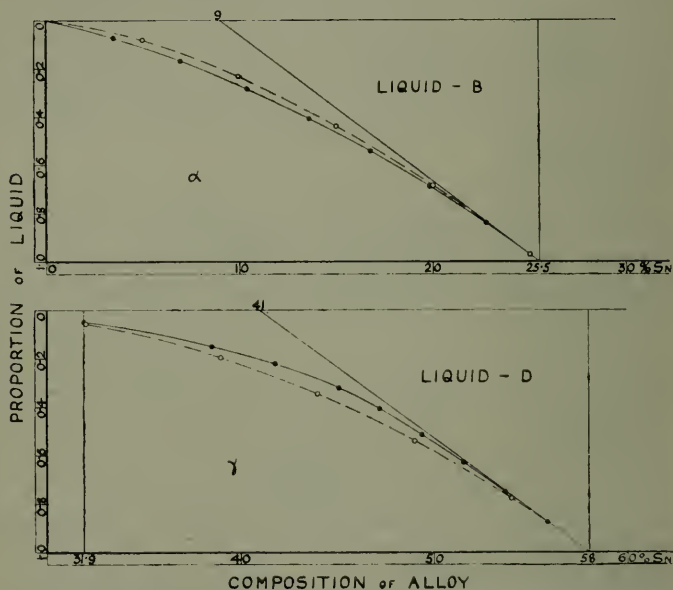
Fig. 5.—Diagrams showing the calculated proportion of liquid in rapidly cooled copper-tin alloys from which a-crystals and γ-crystals separate; ○, when liquidus and solidus are assumed straight; ●, when their actual curved forms are employed.

proportion of liquid in the rapidly cooled alloys is shown carried back to this percentage in the upper middle part of Fig. 4. The proportion of C-liquid in the rapidly cooled alloy B is 0·178 of the whole.

Between 31·9 and 58 per cent. of tin, where the primary crystals are designated γ, the curvature of the liquidus is fairly uniform, but that of the solidus is not so. It is necessary to choose mixtures at such intervals as correspond

with quite short sections of the strongly curved part of the solidus; nine have been taken, containing 31·9, 38·55, 41·8, 45·1, 47·2, 49·4, 51·55, 53·7, and 55·85 per cent. of tin respectively. The calculated results are exhibited by a curve as before, shown in the upper right-hand part of Fig. 4, and, similarly to the case of the β-crystallization, this curve is dotted back to 25·7 per cent. of tin, the position of the intersection of the first portions of the solidus and liquidus. The proportion of *D*-liquid in the rapidly cooled alloy *C* is 0·048.

For the branch of the liquidus immediately to the right of *D* the crystallizing substance is the compound Cu_3Sn, which separates in a sensibly pure state from the liquid. Under the limitations imposed by the initial assumptions, no change of constitution is caused here by varying the rate of cooling. This series of alloys is therefore left at the point *D*.

It is a matter of some interest to emphasize the necessity of allowing for curvature in the calculations by showing the differences in the results obtained when liquidus and solidus are assumed straight. In Fig. 5 the proportions of liquid and solid for the *a* and *γ* periods of crystallization, as drawn already in Fig. 4, are compared, on an enlarged scale, with those calculated when the lines *AB* in the one case, and *CD*, cc_1 in the other are assumed straight; the former results are shown by full dots and lines, and the latter by open circles and broken lines. For the *a*-crystallization the curvature of the liquidus *AB* has the effect of diminishing the amount of solid formed during a small fall of temperature, as compared with what would be formed if *AB* were straight; in the upper diagram of Fig. 5, therefore, the continuous curve lies below the dotted one. For the *γ*-crystallization the curvature of the liquidus *CD* would have an effect similar to that of *AB*, but this is more than nullified by the strong reverse curvature of the solidus cc_1, and in the lower diagram of Fig. 5 the continuous curve lies above the dotted one. In both cases the proportional error caused by assuming the curved lines of the equilibrium diagram to be straight is seen to be very large, more especially for *γ*; it follows, of course, that a small correction in the shape of the lines may make

an important change in the calculated constitution of the rapidly cooled alloys.

So far the transformations which take place in the partly liquid alloys have been neglected. Under conditions of equilibrium there is a transition of $\alpha + B$ to β at the temperature aB, of $\beta + C$ to γ at the temperature b_1C, and of γ to $Cu_3Sn + D$ at the temperature d_1D. It is in accordance with the original assumptions to consider the first two of these changes to be suppressed when the rate of cooling is indefinitely rapid. Now an alloy containing less than 25·5 per cent. of tin, at the temperature aB, consists of α-crystals and B-liquid. If the rate of cooling is very rapid the B-liquid has no time to react with the α-crystals to form β-crystals, but it behaves as if it were an independent liquid alloy of composition B, and deposits β-crystals as if the α-crystals did not form part of the mixture. At the temperature b_1C a quantity of C-liquid, which as stated already is 0·178 of the B-liquid, is left. Similarly, any liquid left at C deposits γ-crystals independently of the previous formation of α and β, and leaves a residue of 0·048 of its own weight of D-liquid at the temperature d_1D.

The very slowly cooled alloys experience changes after they have become completely solid, but for the present purpose these are not considered. The upper diagram of Fig. 6 shows the constitution of just solid alloys when in a condition of equilibrium; the temperature of each alloy containing less than 41 per cent. of tin is supposed to be just below that of its proper point on the broken solidus line $Aabb_1cc_1$, Fig. 4, and for those containing 41 to 58 per cent. of tin the temperature is supposed to be just above dc_1D, so that no account is taken of the formation of Cu_3Sn. This arrangement is made merely for convenience in comparing results. The lower diagram of Fig. 6 represents the constitution of the very rapidly cooled alloys; the temperature is supposed to be just above d_1D, and the extreme rapidity of cooling is supposed to preclude any change in the solid phases. The two diagrams, taken together, show what profound changes of constitution may be caused by rapid cooling. Take, for instance, an alloy containing 7 per cent. of tin; when solid

and in a condition of equilibrium this consists entirely of homogeneous α-crystals, but when very rapidly cooled to just above the temperature of d_1D it would consist of roughly 83 per cent. of α, 14 per cent. of β, 2·9 per cent. of γ, and 0·1 per cent. would still remain liquid. Or choose an alloy containing 20 per cent. of tin; under equilibrium conditions,
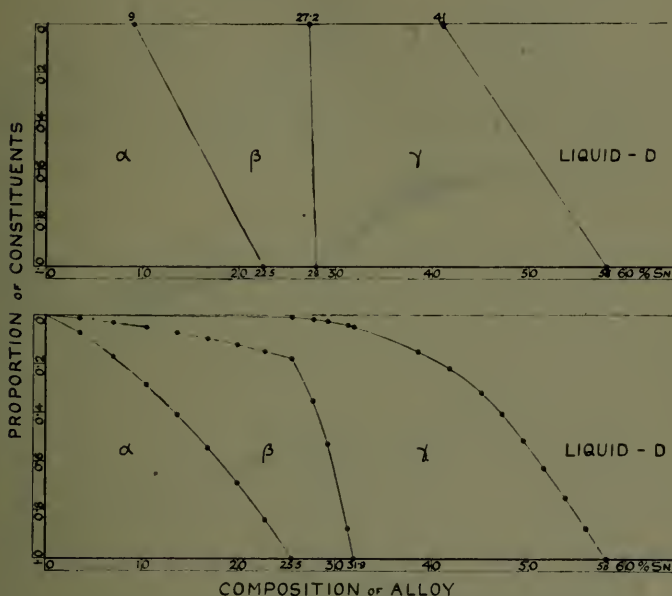
FIG. 6.—Diagrams showing, above, the constitution of copper-tin alloys in a condition of equilibrium, and, below, their constitution when very rapidly cooled.

at a temperature just below that of αB, this consists of 18·5 per cent. of α and 81·5 per cent. of β; but when rapidly cooled to the same temperature it would contain about 31 per cent. of α, 57 per cent. of β, and 12 per cent. of liquid; if quickly cooled to just above d_1D this liquid would deposit $11\frac{1}{2}$ per cent. of γ, the remaining $\frac{1}{2}$ per cent. of the alloy being still liquid. Further instances may be taken from the diagrams.

III. The Copper-Zinc Alloys.

The portion of the equilibrium diagram to be considered is drawn in Fig. 7 from the experimental results of Roberts-Austen, of Shepherd, and of Tafel.* The compositions corresponding with the various critical points are,

$$a = 29\cdot0; \qquad b = 36\cdot0; \qquad B = 37\cdot0;$$
$$b_1 = 55\cdot0; \qquad c = 60\cdot7; \qquad C = 61\cdot0;$$

per cent. of zinc. As in the case of the copper-tin alloys, there may be small errors in the positions of these points.
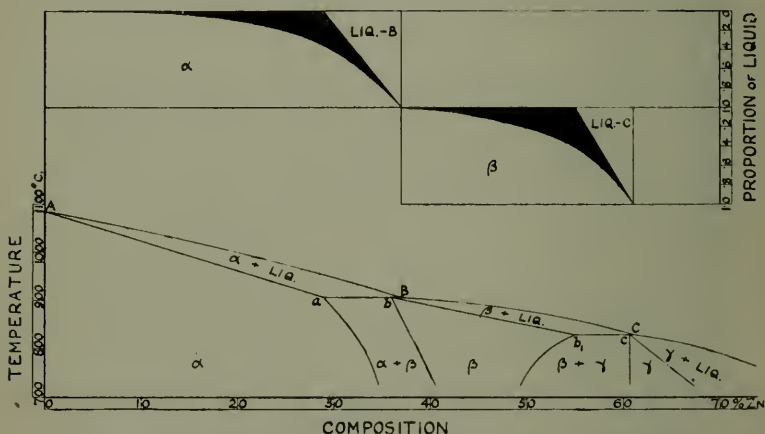
FIG. 7.—Part of equilibrium diagram for copper-zinc alloys, and diagrams indicating the increase in the proportion of liquid caused by rapidly cooling alloys which reject α- and β-crystals respectively.

The solidus curves for α- and β-crystals probably differ little from straight lines; the forms of the liquidus curves are probably not quite so accurately determined as those of copper-tin. Few of the alloys containing more than 60 per cent. of zinc are of practical importance, and the corresponding part of the equilibrium diagram is somewhat defective, so that the crystallization of only α and β is considered here.

* Roberts-Austen, *Proceedings of the Institution of Mechanical Engineers*, 1897, p. 43. Shepherd, *Journal of Physical Chemistry*, 1904, vol. viii. p. 421. Tafel, *Metallurgie*, 1908, vol. v. pp. 343, 375, 413.

The α-crystals separate from liquid alloys containing less than 37 per cent. of zinc. The curvature of the branch *AB* of the liquidus is approximately uniform, and the line does not depart greatly from straightness; it was divided into four equal parts, giving three alloys containing 9·3, 18·65, and 27·85 per cent. of zinc respectively. These are probably sufficient for the present purpose. The results are plotted,
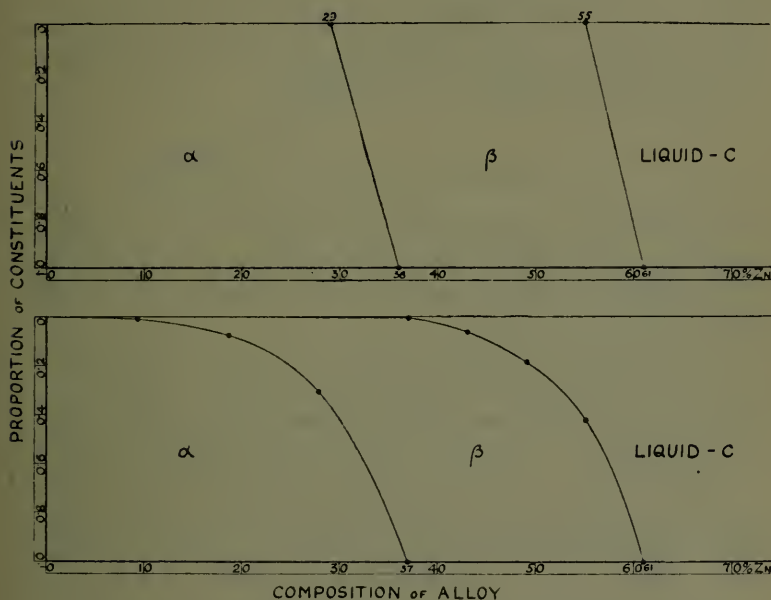
Fig. 8.—Diagrams showing, above, the constitution of copper-zinc alloys in a condition of equilibrium, and, below, their constitution when very rapidly cooled.

in the same manner as before, in the upper part of Fig. 7. A similar procedure was followed for the branch *BC*. The proportion of *C*-liquid left in the rapidly cooled alloy *B* is very small, only 0·0043. Comparison of the curves shown in Fig. 7 with those obtained when *AB* and *BC* are assumed straight, gives results like that of Fig. 5, for the copper-tin α-crystals; the correct figures correspond with a greater proportion of liquid than when the liquidus is assumed straight,

the difference in the case of the α-crystals being small, but for β considerable.

In Fig. 8 the constitutions of slowly and of rapidly cooled alloys are compared, just as in Fig. 6. Each slowly cooled alloy containing less than 55 per cent. of zinc is supposed to be at a temperature just below the corresponding point on $Aabb_1$, and those containing from 55 to 61 per cent. of zinc at a temperature just above b_1C; the quickly cooled alloys are also supposed to be at the latter temperature. The results are not so striking as in the case of the copper-tin alloys, chiefly on account of the closeness of the points b and B, Fig. 7, to each other.

IV. The Copper-Nickel Alloys.

The method of the preceding paragraphs may be extended to alloys of two metals which show complete mutual solubility when solid. A suitable example is afforded by the copper-nickel alloys.

The equilibrium diagram, Fig. 9, is due to Guertler and Tammann, to Kurnakow and Zemczuzny,* and to Tafel.† The curvature of liquidus and solidus is greatest in the middle region of the diagram. The nine alloys for which the calculations have been made have their freezing-points situated at equal intervals between the freezing-point of nickel and that of copper, and contain 6·6, 13·6, 20·7, 28·2, 37·1, 46·9, 57·8, 69·0, and 82·5 per cent. of nickel respectively; a somewhat better choice, more in accordance with the variations of curvature, might have been made.

There is now, of course, no eutectic or transition temperature for the partly liquid alloys, and mixtures cooled with extreme rapidity would only become completely solid at the freezing-point of copper, according to the original assumptions. The process of solidification, however, may be supposed interrupted at any desired temperature, and the differences of constitution between slowly and rapidly cooled alloys at

* Guertler and Tammann, *Zeitschrift für anorganische Chemie*, 1907, vol. lii. p. 25. Kurnakow and Zemczuzny, *Zeitschrift für anorganische Chemie*, 1907, vol. liv. p. 151.
† Tafel, *loc. cit.*

this temperature may be represented by a diagram of the same form as in previous examples. In the upper part of Fig. 9, such diagrams have been drawn for the four temperatures, 1118°, 1187°, 1256°, and 1324°, corresponding with the freezing-points of the alloys numbered I., III., V., and VII. respectively. These diagrams should require no explanation.
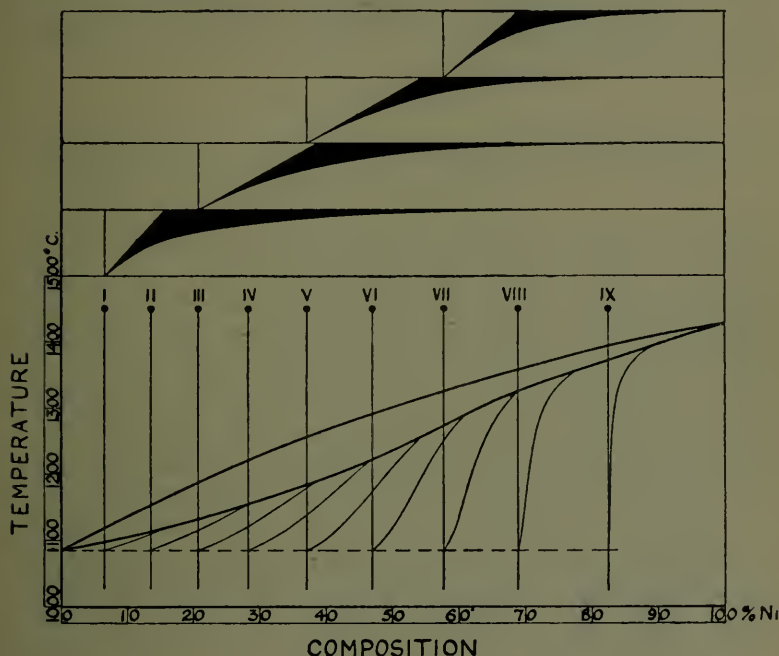
Fig. 9.—Equilibrium diagram for copper-nickel alloys; diagrams showing the increase in the proportion of liquid in rapidly cooled alloys at four selected temperatures; and the apparent solidus curves of nine chosen alloys when rapidly cooled.

Below the real solidus has been plotted for each alloy the apparent solidus, that is, the curve which represents the average composition of the solid portion of the rapidly cooled alloy at all temperatures during the period of partial solidification, just as was done for the lead-tin alloys in Fig. 8 * of the previous paper. All alloys of the series, when just solid and in a condition of equilibrium, are formed of homo-

* *Journal of the Institute of Metals*, No. 1, 1913, vol. ix. p. 148.

geneous crystals. In each quickly cooled alloy the average composition of the crystals gradually approaches that of the whole mixture as more and more of the mass becomes solid. The shape of the apparent solidus for alloy IX. is similar to those drawn for the lead-tin alloys, but mixtures containing more copper than IX. show a reversed curvature of the lower part of the apparent solidus, corresponding with the reversed inclination of the real solidus to the liquidus at the copper end of the diagram.

V. Calculation of the Constitution of Alloys cooled at Ordinary Rates.

For an actual alloy the rate of cooling lies between the extreme slowness necessary for equilibrium and the extreme rapidity for which the preceding calculations have been made. The proportion of liquid in the mixture at any temperature during the period of partial solidification also lies between those calculated for the two extreme conditions. The difficulty of specifying the rate of cooling at a point in a mass of metal has been mentioned already, but it may be possible to determine the proportion of liquid or of eutectic in each of a series of alloys, all cooled under approximately similar conditions and at a rate within the range of those realized in manufacturing or experimental work, without determining what this rate is.

The examination of many of the experimental results emanating from Professor Tammann's laboratory shows that the shape of the curve which represents the proportion of eutectic in the just solid alloys of a series cooled at a moderately slow rate is of a form similar to that obtained by calculation for very rapid cooling. Moreover, the curves plotted from the figures in the various columns of Table I.* are all of similar shape. It is therefore probable that the curves which represent the proportion of liquid or of eutectic for different rates of cooling can be referred to one general equation. Now for equilibrium conditions the curve is a

* *Loc. cit.*, p. 138.

straight line. If, as before, E is the proportion of eutectic in the just solid alloy, X is the composition of the alloy, X_E the composition of the eutectic, and X_S that of the saturated solid solution, the expression (4)* may be rewritten as,

$$E \text{ (slow cooling)} = \frac{X - X_S}{X_E - X_S} \quad . \quad . \quad . \quad . \quad . \quad (4a)$$

And for extremely rapid cooling the expression (7b),

$$E \text{ (rapid cooling)} = \left(\frac{X}{X_E}\right)^{\frac{X_E}{X_E - X_S}}$$

has been given already. These are two particular cases of the general equation

$$E = \left(\frac{X - x}{X_E - x}\right)^{\frac{X_E - x}{X_E - X_S}} \quad . \quad . \quad . \quad . \quad . \quad (12)$$

where x is a quantity which varies with the rate of cooling, and has a value between zero and X_S. For very slow cooling, $x = X_S$, and (12) reduces to (4a). For very rapid cooling, $x = 0$, and (12) reduces to (7b). At any intermediate rate the curve cuts the axis of composition at a point between zero and X_S, and the composition for this point is x, since by putting $x = X$ in (12) the value of E becomes zero.

For cases in which the curvature of liquidus and solidus is negligible, the expression (12) is regarded as representing very closely the proportion of liquid in an alloy during the process of solidification for all rates of cooling, but this result requires experimental verification, since it has been deduced only indirectly from physical facts. There is certainly a close agreement between the quantities calculated from (12) and those given in the various columns of Table I., but even with the rate specified there as "10 steps" the conditions approximate far more closely to great rapidity than to great slowness. In Fig. 10 three curves have been drawn for the lead-tin alloys from equation (12), between the curve representing the proportion of liquid in very rapidly cooled alloys and the straight line representing the conditions for very slowly cooled ones; the values of x chosen for the new curves,

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* *Loc. cit.*, p. 130.

which are drawn with fine lines, are 4, 8, and 12 per cent. of tin. For cases of transition similar curves can be drawn. Curves of this kind have been compared with some of the experimental curves published from Professor Tammann's laboratory, but the various defects of the latter are too great to allow them to be employed to decide whether equation (12) accurately represents the conditions prevailing at inter-
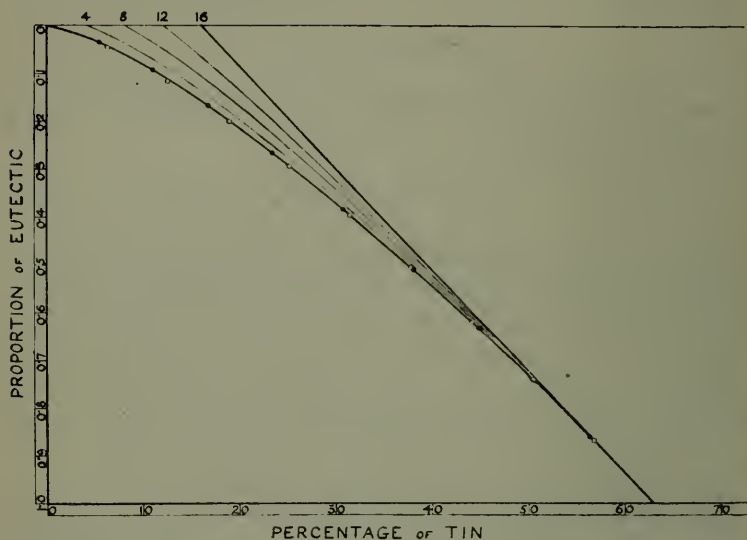
Fig. 10.—Diagram showing the calculated proportion of eutectic in lead-tin alloys cooled with extreme rapidity; ○, when liquidus is assumed straight; ●, when true curved form of liquidus is taken. The fine lines through 4, 8, and 12 per cent. of tin indicate the calculated proportion of eutectic for three intermediate rates of cooling, and the straight line through 16 per cent. of tin shows the equilibrium proportion of eutectic.

mediate rates of cooling. It has to be remembered also that the rate of cooling of an actual mass of metal, except when special precautions are taken, is very far from uniform, and that the value of x is therefore different for different parts of the mass.

The proportion of liquid present in an alloy cooled at a moderate rate, at a temperature between its freezing-point and its eutectic or transition point, cannot be found by the

present method unless some assumption be made as to the manner in which the quantity x varies with the temperature. Thus the sectional method of calculation, employed in the case of rapid cooling when the curvature of liquidus and solidus is to be allowed for, cannot be used in conjunction with (12) to get corresponding results for moderate rates of cooling without some such arbitrary assumption.

A more promising method of dealing with cases in which the curvature is considerable consists in expressing the numerical results, obtained by substituting variable values of X_E and X_S in (7b), in terms of the actual fixed values of these quantities. The index of the fraction

$$\left(\frac{X}{X_E}\right)$$

is then found to vary with X, instead of being constant as it is when liquidus and solidus are straight. To take an example, the variation in the index for the copper-tin a-crystallization is represented very closely by a straight line, and the proportion of liquid in the rapidly cooled alloys is, very nearly,

$$E=\left(\frac{X}{X_E}\right)^{0\cdot83\left(\frac{X_E}{X_E-X_S}\right)+0\cdot29\left(\frac{X}{X_E}\right)} \quad . \quad . \quad . \quad . \quad (13)$$

where $X_E = 25 \cdot 5$ and $X_S = 9 \cdot 0$ per cent. of tin. But another difficulty now presents itself, namely, to insert the quantity x into (13), so as to give an expression corresponding to (12), representing the conditions for intermediate rates of cooling. An essential condition is that this expression shall reduce to (4a) when $x = X_S$. It follows that the multipliers $0\cdot83$ and $0\cdot29$ in (13) must vary with the rate of cooling. Suggestions as to the manner in which they vary might be made, but this part of the subject really requires some experimental work to put it on a sound basis.

VI. Summary.

The method of the previous investigation has been extended so as to allow of obtaining a closely accurate determination of the proportion of liquid present in a quickly cooled alloy

in cases where the solidus and liquidus are considerably curved.

Calculations have been made for the more important alloys of the copper-tin and copper-zinc series, and for the copper-nickel series. The important effect of the curvature of solidus and liquidus upon the constitution of rapidly cooled copper-tin alloys has been shown.

A formula has been devised, from which it is probable that the constitution of alloys cooled at ordinary moderate rates can be determined with fair accuracy, when the liquidus and solidus are not much curved.

THE FIFTH ANNUAL DINNER

THE Fifth Annual Dinner was held at the Criterion Restaurant, Piccadilly, W., on Tuesday evening, March 17, 1914, Engineer Vice-Admiral Sir HENRY J. ORAM, K.C.B., F.R.S., President, occupying the chair.

There was an attendance of guests and members numbering about 160, amongst whom were :—

Sir H. FREDERICK DONALDSON, K.C.B. (*Chief Superintendent, Royal Ordnance Factory, Woolwich, and President, Institution of Mechanical Engineers*).

Mr. BEDFORD MCNEILL (*President, Institution of Mining and Metallurgy*).

Dr. R. T. GLAZEBROOK, C.B., F.R.S. (*Director, National Physical Laboratory*).

Sir THOMAS HENRY ELLIOTT, K.C.B. (*Deputy-Master, The Royal Mint*).

Colonel Sir HILARO W. W. BARLOW, Bart., R.A., C.B. (*Superintendent, Royal Laboratory, Royal Arsenal, Woolwich*).

Sir FREDERICK W. BLACK, Kt., C.B. (*Director of Naval Contracts, The Admiralty*).

Mr. MERVYN O'GORMAN, C.B. (*Superintendent, Royal Aircraft Factory, South Farnborough*).

Mr. LESLIE S. ROBERTSON (*Secretary, Engineering Standards Committee*).

Professor E. G. COKER, M.A., D.Sc. (*Professor of Mechanical Engineering, City and Guilds of London Institute*).

Professor RAPHAEL MELDOLA, F.R.S. (*President, The Institute of Chemistry of Great Britain and Ireland*).

Dr. RUDOLPH MESSEL (*President, The Society of Chemical Industry*).

Mr. W. D. CARÖE (*Master, The Worshipful Company of Plumbers*).

Mr. W. DIXON (*President, The West of Scotland Iron and Steel Institute*).

Mr. C. H. WORDINGHAM (*Superintending Electrical Engineer, The Admiralty*).

Mr. SYDNEY A. GIMSON (*President, The British Foundrymen's Association*).

Professor A. K. HUNTINGTON, Assoc.R.S.M. (*Past-President*).

Professor W. GOWLAND, F.R.S., Assoc.R.S.M. (*Past-President*).

Dr. W. ROSENHAIN, F.R.S. (*Member of Council*).

Sir WILLIAM E. SMITH, C.B. (*Member of Council*).

Professor T. TURNER, M.Sc. (*Vice-President and Honorary Treasurer*).

Mr. BOEDDICKER (*Vice-President*).

Dr. G. T. BEILBY, F.R.S. (*Member of Council*).

The CHAIRMAN gave the toast of " His Majesty the King," which was drunk with musical honours.

" THE INSTITUTE OF METALS."

Mr. BEDFORD MCNEILL (President, the Institution of Mining and Metallurgy), in proposing the toast, said : I rise with very great pleasure to propose the toast of " The Institute of Metals," one of the youngest, if not the youngest, of our British technical societies. Although you are only five years old, I think I can say that you manifest every sign of a robust constitution, and I can certainly congratulate those who were

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responsible for bringing you into existence. You had the very great privilege of having as your first President Sir William White, the celebrated naval architect. We know his memory will be cherished not only in this Institute, but also in that magnificent service which he served so faithfully and so well.

Your Institute is another example of that specialization of work and endeavour which is absolutely necessary to meet the needs of modern times. Your progress is eloquent, not only of the necessity there was for your existence, but it has made us all realize what a vast field there is for investigation and research, and what enormous possibilities and benefits are opened up to the technical community by the full and frank discussion of "Cause and effect," which is possible at the meetings of your Society. I have very carefully looked through the list of contents of the ten volumes of Transactions you have already published, and I am more than ever inclined to agree with the learned William Pryce. William Pryce wrote in his famous *Mineralogia Cornubiensis*, which was published in 1778, as follows : " It is very probable that the nature and use of metals was not revealed to Adam in his state of innocence. The toil and labour necessary to procure and use those implements of the Iron Age could not be known till they were made part of the curse incurred by his fall." It seems almost impossible to believe in these days of scientific precision that we are only a few short years removed from the time when all inanimate matter was divided into four simple classes —earth, stone, metals, and juices—and when it was gravely recorded that in Scotland " when pieces of old ships or fruit fall into the sea they turn into living ducks."

I should like to express my personal appreciation of the compliment that has been conferred upon my Institution by asking me to propose this important toast. In my capacity as President of the elder sister society I should like to congratulate you on having commenced life by clearly defining your objects. In my Institution it has been necessary recently that we should clearly define our sphere of influence. You are saved any discussion, because you have laid down a clear-cut definition to begin with. I need not point out to you that our two Institutions are closely connected. You exercise your skill and industry on the products which the skill and industry of the members of my Institution produce. I should like particularly to urge the advantages to the community that must result, and are, in fact, resulting from the division of labour amongst the younger scientific and technical societies, especially when it is united with complete freedom and entire independence of action. I suppose there was no more bitter controversy than that which ensued at the beginning of the last century when the Geological Society determined to be absolutely independent of the Royal Society, and yet we find that in 1903 Sir William Huggins is able to say, " The scientific world as well as the Geological Society itself have good reason to rejoice over the wise and far-seeing policy of its founders and original members when they decided to leave the young society free to grow and to develop its powers untrammelled by any obligation to any other body." And now what do we see to-day? That most eminent geologist, Sir

Archibald Geikie, a Past-President, of the Geological Society, occupying the proudest position that any scientific man can attain to, namely, the Presidency of the Royal Society.

Mr. Chairman, I should like just to say two things. I should like first to congratulate you upon your Institute having accomplished during the first five years of its existence such a splendid amount of work as is recorded in your Transactions, a record which enables one to surely predict for your Institute that in the years to come you will still further increase in usefulness and render still more valuable services to the community. Secondly, I should like to congratulate your members on having as their President a man who, as part of a strenuous career in the service of his country, now occupies the very distinguished and most responsible position as Engineer-in-Chief to the Fleet.

Gentlemen, I have much pleasure in submitting to you the toast of " The Institute of Metals," and I couple with it the name of your Chairman and President, Sir Henry John Oram.

Sir HENRY J. ORAM, K.C.B., F.R.S. (President), in responding to the toast, said : I must thank Mr. Bedford McNeill most heartily on behalf of the Institute of Metals for the kind and eulogistic manner in which he has proposed the toast, and also you, gentlemen, for the very hearty response which you have made to it. The history of our Institute is well known to most members and guests present. I believe we cover a wider field of research and utility than any other similar technical institution, and we have, I think, made an excellent start on the road which leads to our goal. Although the country is so full of technical societies, the reception this one met with at its birth showed that there was room for still another, and we have much to be thankful for in the absence of jealousy and the cordial co-operation we experience from other similar institutions. I must not, however, trench on the ground allotted to my friend Dr. Beilby in saying too much about kindred associations.

In our papers and Journal we are, I think, as it were, breaking comparatively new ground, and are different from older societies in that respect. The number of technical societies in existence in this country is very large, and many of them also have their separate district branches in various localities where, as in the parent Society, papers must be read if only to stir up local enthusiasm in the Society's proceedings. The output of technical literature is consequently really appalling, and beyond the possibilities of any particular person to deal with or read. There is, I think, a great want of some sort of clearing-house for papers, where the wheat and the chaff could be separated, where the scissors and paste and " pot-boiling " varieties could be eliminated from further notice and the remaining 10 per cent. or so presented to us in some convenient form. What I am coming to is this : that in this residue I think the work of the Institute of Metals would be largely represented.

Now as regards our membership, respecting which we have heard a good deal this afternoon, this is steadily increasing, and as we know that healthy children should not grow too fast, our rate of progress in that respect may be regarded as indicating healthy and robust youth. We

do not adopt any undignified methods of advertising; we do not require such aids. A few days ago, however, I met an engineering friend and introduced the subject of the Institute of Metals to his notice. I was very much surprised at his remarking that he had never heard of the Institute of Metals. He thought I was the President of the Iron and Steel Institute—"that being more in your line," as he said. The gentleman will shortly be a member of the Institute of Metals, when no doubt he will know a lot more about our proceedings. I certainly hope that our members will take great care in the future that similar cases of gross ignorance do not exist.

I think everyone admits that the Institute of Metals is doing good work, and I wish to dwell to-night on the fact that they could do a great deal more if they had more funds. As I remarked this afternoon, our wealthy friends who are interested in metallurgy would find a worthy channel for contributions or an endowment in the research work being undertaken or to be undertaken by the Institute of Metals.

" Kindred Societies and Institutions."

Dr. G. T. Beilby, F.R.S. (Member of Council), in proposing the toast, said : I think there was a strong undercurrent this afternoon in our President's address, which suggested that he was one of those who believed greatly in the virtues of association. He told us some most interesting things about the procedure by which the members of his staff, and the members of the department with which he is connected, had gradually improved certain materials which are required in the construction of marine engines, and he showed us that that improvement was made by association and co-operation between the experts— between the engineers who were going to use the machinery, and the manufacturers who were making the raw material. To many people, I believe, it was quite a new idea that the Department of the Admiralty was so very enlightened. To many, I believe, this came as a surprise ; but there are also many members who already knew that enlightened methods now prevail in the department over which our President presides. Mr. Bedford McNeill, in proposing the toast of the Institute, told us that the modern tendency is rather in the other direction—that the modern tendency among technical and scientific societies is all towards specialization. Now, gentlemen, I think it is absolutely necessary that we must have both co-operation and specialization, and I think it is fortunate for us that our President is a man who so fully appreciates what can be done by bringing the right men together from all sides to do a particular piece of work.

In giving you this evening the toast of "Kindred Institutions," I think we must look upon it that in including kindred societies in our pleasant gathering, it is our wish to work on the great principle of association among specialists of all kinds. It is our desire that the members of those societies should come to our gatherings, should be interested in what we are doing, and that we, as members, as many of

us are, of kindred societies, should hope to gain a great deal by our association with those who are working on lines other than our own.

We have to-night with us distinguished representatives of many of these kindred societies. In the list which has been prepared for our use, and to which I must naturally adhere, I have been asked to associate two names with the toast—those of Dr. R. T. Glazebrook and of Professor R. Meldola. Dr. Glazebrook stands for us as a remarkable illustration of what the interest of a purely scientific society like the Royal Society can do when it is wisely directed towards the utilization of natural knowledge. The Royal Society was founded " for the promotion of natural knowledge." Fortunately, the President and Council of that body have from time to time recognized that the mere search for natural knowledge is not all that is required, but that the application of that natural knowledge to the uses of man is quite within its province, and more than fourteen years ago, when the Royal Society was invited to take part in initiating the movement for the founding of a National Physical Laboratory, it rose most remarkably to that great occasion. The result of that movement is before us to-day in this splendid institution, the National Physical Laboratory, which is presided over by Dr. Glazebrook. To those who had the honour and privilege of being concerned in the initiation of this Institution all these years ago, it is a matter of great satisfaction that this magnificent Institution has grown out of these first small beginnings ; and in bringing about this result, there is no doubt whatever in our minds that it has been largely due to the stimulating influence and guidance of Dr. Glazebrook, who has got round him a brilliant and an energetic staff of younger men, who are all pushing forward the departments under their charge with every energy, and, we are proud to say, with every success.

The other representative with whom this toast is associated is Professor Meldola. Professor Meldola, as everyone here knows, is a great chemist. He is an absolutely unique representative of kindred chemical societies, for he has been in turn President of the Chemical Society, President of the Society of Chemical Industry, and now he is President of the Institute of Chemistry. In his person we have the opportunity of including at once three kindred societies. Professor Meldola has always shown a very great interest not only in pure chemistry, but in its application to the arts. He has done very good work in that direction himself, and as President of the Society of Chemical Industry and of the Institute of Chemistry, he has done a very great deal in promoting the better education of chemists who are preparing to enter industrial and professional life.

Now, gentlemen, I am afraid I have not followed the good example of previous speakers in speaking very briefly, but I would ask you now to drink to the health of the Kindred Societies, associating the toast with the names of Dr. R. T. Glazebrook and Professor Meldola.

Dr. R. T. Glazebrook, C.B., F.R.S. (Director, the National Physical Laboratory), in responding to the toast, said : I have to thank you, Dr. Beilby, very cordially indeed for the kind references you have made, in

proposing this toast, to the National Physical Laboratory, and to the work it is my privilege to do there. I am glad to feel that the Institute of Metals looks upon the National Physical Laboratory as a kindred Institution, and I am particularly grateful to you, Dr. Beilby, for the recognition that you gave to the very great and important work which the Royal Society undertook when, fifteen years ago, it assumed the responsibility of controlling and managing, with the help of the other kindred societies of the country, the work of the Laboratory. The progress of that work has been due in no small measure to the unstinting support that has come from that Society, and from its Fellows, and in addition to the loyal work and co-operation of the staff of the Laboratory.

I may claim in a particular way to be closely connected with the Institute of Metals, for among those—and there are many of them— who have done much for the work of the Laboratory with which I am associated, there is none to whose services we owe more than to those of the late Sir William White, your first President. And among those who worked hard some five or six years ago for the inauguration of this Institute of Metals, and who were to a great extent instrumental in bringing it about, I think I may mention the name of the first holder of a metallurgical post at the Laboratory, Dr. Carpenter; and also that of a distinguished member of your Council, whose services not merely to non-ferrous metals, which are the special subject, I gather, of your Institute, but to the iron and steel industry, will ever be noted, and who is my right-hand man in many of the investigations that go on in the Laboratory—Dr. Rosenhain. So the connection between your Institute and the Laboratory is a very close one, and perhaps it is right and proper that I should be permitted to reply here for kindred Institutions, although I confess, when this morning I took down from my mantleshelf the card which gave me admission to this pleasant gathering, I was appalled at seeing with how many similar Institutions I was very closely connected, and on how many occasions in the near future I was to take part in gatherings of this kind.

Your Institute, gentlemen, has many friends, and, as your President has already said, the subject with which you deal is very large indeed. I do not know that representatives of all the societies here would quite allow that it covers a larger field than those which are included in their activities, but still no doubt it is a very large one, and is connected closely not merely with many branches of science, with metallurgy, and as it used to be called at Cambridge in the old days, with chemistry and other branches of physics, but also with industries of various kinds. Its rapid growth only shows how well those who are responsible for its progress and its work have realized the necessity of a close connection between scientific investigation and scientific inquiry, and the delicate and intricate processes which are now required in the production of metals and materials for use in engineering work and engineering structures. Some years ago we were told, rather too often, I think, that we had to look to our friends across the sea, to our friends in Germany or to our friends in America, to illustrate the manner in which the advances of modern science were being utilized for the progress of industry and of

manufacture. It seems to me that the series of volumes which have issued from this Institute, that the work which is being done in connection with it, and the investigations which are going on under its guidance, show that at any rate now those who are most prominent in the engineering trade and industry of the country have realized and do realize very fully and very wisely that help may come to them, and does come to them, from scientific inquiry and scientific investigation. It is a most important sign, I think, and an indication of future prosperity for the country, that this should be so. I will not attempt to give illustrations. You, Mr. Chairman, know full well the need for inquiry and investigation in the great work with which you are connected, and I should like if I may to thank you very cordially for the kind reference you made to the Laboratory in your address this afternoon, and for the fact that you have entrusted to us from time to time difficult and serious matters of inquiry, and have made use of the assistance that we have been able to give you. I should like at the same time to suggest that it would be well for the Institute—and I am sure that it is the view of those who control its destinies—that so far as its funds and opportunities allow, it should encourage pure science and pure inquiry. Only those who have tried can tell the pleasure and the privilege of discovering new facts, new laws, and new principles, and it is not wise to suppose that the only subjects of inquiry that can be properly stimulated and helped by Institutions such as this, are those which appear to have an immediate return in practical work. There is no need to attempt to give illustrations. Many are well known, and if the Institute of Metals will go on in the way in which it has begun, devoting its energies and its opportunities to the discovery of new facts in science, and to their application to practical life, it will prosper and will merit and deserve the thanks of all lovers of true science, and of all those who are most deeply interested in the welfare and the progress of the country.

I should like to join with Mr. Bedford McNeill, who spoke first in congratulating the Society on what it has done already, and in assuring you, speaking as I am allowed to do for kindred Societies, that the kindred Societies of this country look upon you, their younger sister, in many cases with somewhat envious eyes, because of the progress of the great work you have already been able to do.

Professor R. MELDOLA, F.R.S. (President, the Institute of Chemistry of Great Britain and Ireland), who also responded to the toast, said : I esteem it a great privilege to be allowed to respond on this occasion to the toast of " Kindred Societies." As you have heard from Dr. Beilby, I have had, during the course of my life, to preside over the destiny of several Societies, which, on the present occasion, I think may claim kinship with this Institute of Metals. You have heard from the President of the Institute of Mining and Metallurgy that they concern themselves with the material which is placed at the service of humanity, and when that material is worked up, then the wrought-up material comes within the province of the Institute of Metals. May I venture to interpose between these two stages the subjects represented

by our science of chemistry, and to claim that we think, and we hope, that our science has rendered some service to you? Speaking on behalf of chemical subjects, let me further state that we hope in the future we shall become still more useful and still more intimately associated with your work. Dr. Beilby has in fact struck a note which seems to me of the greatest importance. This question of specialization is one which we have to face with the development of science, both pure and applied. Specialization, I think, may be looked upon as a sign of progress. The capacity of the individual is unfortunately limited. The field which is covered by modern science is so great that specialization is becoming more and more necessary. I remember the time of the birth of this Institute when the usual question was asked, What is the use of it? What scope is there for another Society? Well, I have followed your career in a very humble kind of way, and I am bound to say from what I have seen of that career that you have more than justified your existence. I am sure that such a meeting as you have just had, and which you are now carrying on, is in itself ample testimony to the necessity for the calling into existence of such a body as the Institute of Metals. I have not read those ten volumes to which the President referred, but I have seen many of the detached communications to the Institute, and I am quite prepared to bear out that you have contributed a very fair share of that 10 per cent. of survivable matter which the President mentioned as being the outcome of the activities of the technical societies. The National Physical Laboratory, whose distinguished director has just addressed you, is an institution which fulfils a great national want, and the operations of which are destined for the standardization of the machinery and the apparatus used in all branches of industry. It has, of course, its pure scientific side, with which I am sure we must all sympathize, and which we wish God-speed, but in its applied side it caters for the regularity of the nation. It standardizes contrivances which are used in many different branches of applied science and in various industries. The Institute which I have the honour of representing on the present occasion also discharges its functions towards the community by standardizing the workers. We represent the human side of the subject, and I am not sure whether the time will not come when the technical societies will be called upon to discharge a similar function towards the community, and to ensure that the practitioners in their respective professions are duly qualified people. That is the function of the Institute of Chemistry, which I now represent. The science of chemistry is coming more and more into contact with the needs of the community; positions of great trust and responsibility are dependent upon chemical expert practitioners, and it is necessary that the community should be protected by some organization which guarantees the competency of the practitioners in the same sense that the medical profession guarantees the competency of its practitioners by the Medical Register. The question arises, Will not the time come when all the practitioners who cater for the public good should be men whose qualifications are guaranteed by some organization competent to confer such

qualifications? That is the only way by which we can stamp out charlatanism and incompetency.

Well, gentlemen, at this late hour I have only once again to express my gratitude for being associated with this toast which you have so kindly received. I claim somewhat on the score of antiquity to go back for a number of years, and I may perhaps stand alone in this room at the present time in being able to state that I was a pupil of Percy's at the Royal School of Mines in the early sixties. My interest in metallurgy was first aroused through attending his lectures, and as bearing upon the subject of the difference between the functions of the National Physical Laboratory and the Institute of Chemistry, that the one ensures the standardization of materials and apparatus, and the other the standardization of the men who carry out the work, I may state that there is a story current which perhaps at this hour may be permissible to be related as a personal reminiscence. In Dr. Percy we had a remarkable combination, at least on one occasion, of these two sides—what might be called the material and the spiritual. Dr. Percy had an assistant by the name of Smith—the name is not unfamiliar. Dr. Percy, as we all know, was a tall man of commanding stature. Smith was an extremely small man. He was a devoted worshipper of Percy, and Percy, knowing it, used to treat him with good-natured chaff and bonhomie. It is related on one occasion that Percy came into the laboratory and looked round in his masterly way and said, "Smith—where is Smith?" and a small voice from below was heard to say, "Here, Dr. Percy." Dr. Percy looked round and said, "Good gracious, I thought it was a crucible!" That, sir, is the most intimate relationship between the spiritual and material that I can call to mind, and with that story I will ask you to allow me to conclude these somewhat desultory remarks by once again expressing my extreme gratitude to Dr. Beilby and to you for having allowed me to rise on the present occasion.

"The Guests."

Dr. W. ROSENHAIN, F.R.S. (Member of Council), in proposing the toast, said: I have been charged this evening with the pleasant but rather formidable duty of proposing the toast of "Our Guests." The guests are to a large extent the chief objects of interest at a gathering like this; they are almost as important as the menu. Now one might inquire—I do not say that any of you here present would inquire, as it is quite obvious to all of you—but if you were guests yourselves you would inquire why you had been asked. There are many reasons why guests are asked by other societies. Some societies occasionally ask their guests out of a lively sense of favours to come; it is a sort of anticipatory sense of gratitude. Sometimes they ask them because they want to punish them; they want to make them give speeches or listen to speeches. Well, if you leave those reasons out, all the rest are applicable to our guests to-night. Really, the list of our guests is a formidable one, and if I may again strike that self-congratulatory note which has been struck so persistently to-night, I would say

that I think the list of guests is such as not only to add lustre to this gathering, but is an indication of the growing importance and standing of this Institute. It is something to our record to have succeeded in assembling round our board such a gathering as we see to-night. We have here representatives of the two great constructive departments of the Government—constructive, I mean, from the engineering point of view —the War Department and the Admiralty. I suppose ultimately their aim is not altogether constructive, but from our point of view they are constructive. We have here gentlemen representing the various interests of the War Department. We have Colonel Sir Hilaro Barlow, the representative of the Royal Laboratory at Woolwich—a Laboratory which is surely named in a very curious fashion, for it is a place where, I think, people really make things. Then we have Sir Frederick Donaldson ; I shall reserve him for a little later. We have Mr. O'Gorman, of the Royal Aircraft Factory. Then from the Admiralty we have Sir Frederick Black and Mr. Wordingham, representing.two very important sections of the constructive activities of that great department. Then we have from another constructive department of the Government service Sir T. H. Elliott, the Deputy-Master of the Mint. Well, gentlemen, I am sure we are all very glad to see him here, because he presides over a branch of metallurgical industry with whose products most of us have only a passing acquaintance ! Personally, I have had the privilege of a passing acquaintance with the particular product of that industry in the form of a bar of extremely pure gold which was kindly prepared for us by Dr. Rose, and which, in a fractured condition, I was able to display to the gathering of this Institute in Ghent. That is only one example of the kindly co-operation which the activities of this Institute and of the National Physical Laboratory receive from many important quarters. From other bodies not immediately connected with the Government we have the representative of Lloyd's Register in Professor W. Abell ; we have from the City and Guilds of London Institute Professor Coker. Professor Coker's work is known to all those who are interested in the construction of objects of metal. He has developed a method of his own by making models of a transparent substance, xylonite, straining them in the same way as the real objects are strained, and then looking through them with the polariscope in order to find the distribution of the strains. That is not only an extremely elegant method, but it leads to very beautiful demonstrations of very brilliant colours. As regards other societies, a good deal has been said about them as such by Dr. Beilby, and I will not in the least attempt to traverse that ground again. We were to have been favoured to-night with the presence of Dr. Cooper, the President of the Iron and Steel Institute, but I understand he is unfortunately unwell, and has been prevented from coming for that reason. We have, however, with us the President of the West of Scotland Iron and Steel Institute, Mr. Dixon, and Mr. Gimson, the President of the British Foundrymen's Association. The British Foundrymen's Association, of course, includes a great many of those interested in the casting of non-ferrous metals, but very largely it is concerned with iron-founding. Now that leads me to remark that specialization between ferrous and non-ferrous metals, of which this

Institute, in its complementary position towards the Iron and Steel Institute, is typical, is a very wise and a very good and a very necessary thing, because there are many problems which are special and peculiar to the non-ferrous metals, and others again which are entirely peculiar to the alloys of iron. But, on the other hand, there is this danger, that we should lose sight of the very great analogies, of the really very close relationship, which exist between the physical metallurgy of all metals, and that, after all, iron and steel are alloys just as brass and bronze are alloys, and that the same laws of physical chemistry, the same fundamental principles of physics and chemistry, apply to both, and have to be studied equally in their application to metallic bodies of all kinds. Therefore, much as we should rejoice in the independent growth of our Institution, and in the current prosperity of the Iron and Steel Institute, we should look for very close co-operation and close co-ordination of facts and results between the two.

As regards chemistry, I think little more need be said. We have here distinguished representatives of the chemical societies. We have had the pleasure of hearing Professor Meldola, and Dr. Rudolf Messel is with us as representative of the Society of Chemical Industry. I should like to say that on the Nomenclature Committee of this Institute we have had representatives of many of these societies and institutions whose Presidents we are happy to welcome here to-night. They have afforded us most cordial and valuable assistance, and none more so than the representative of the Society of Chemical Industry.

Now I come to the Institution of Mechanical Engineers, which is represented here by Sir Frederick Donaldson, with whose name I couple the toast. That is particularly appropriate, because the Institute of Metals owes a very considerable debt of gratitude to the Institution of Mechanical Engineers. I am referring here not only to the material indebtedness for the loan of their building, not on one occasion, but on every occasion—yet there is something more than that. The Mechanical Engineers a good many years ago initiated the Alloys Research Committee, and began, in the earlier days of that Committee, under the work of the late Sir William Roberts-Austen, a series of researches which I think it is not too much to say, so far as the first five or six reports are concerned, went far towards laying the foundation in this country of that science of physical metallurgy of which this Institute is to a very large extent the visible and outward expression at the present day. For that our Institute owes a lasting debt of gratitude to the Institution of Mechanical Engineers. Sir Henry Oram in his remarks suggested the necessity for a clearing-house for the products of research work and for papers generally. No doubt there is a great need for something of that sort, but it is only one step in a process which has been foreshadowed by one of our guests this evening. Sir Frederick Donaldson, in his Presidential Address to the Institute of Mechanical Engineers, set forth the desirability of co-ordination, a sort of clearing-house, for research itself—not only of the works and the papers in which the results are expressed, but some co-ordination of the work before it is undertaken or while it is being done. That proposal has now taken material shape in a

Committee to which this Institute has been privileged to send representatives ; and it is not one of the least things which this Institution, with its interest in scientific and technological research, owes to Sir Frederick Donaldson.

Gentlemen, I have yet another name to couple with this toast—that of Mr. Leslie Robertson. Mr. Leslie Robertson is put down on our list here as Secretary of the Engineering Standards Committee, and as such Mr. Leslie Robertson is no doubt most widely known. He happens also at the present moment to be the Master of one of the City Companies—the Patten Makers. It would have been very nice if I had been innocent enough to make the mistake, which I believe was made by no less a person than a member of the present Government, of thinking that the name was "pattern" maker. It would have been so very, very appropriate for this gathering. Unfortunately I happen to have read in the newspapers that it was a mistake, so I cannot fall into it conveniently. However, while I mention the City Companies, I must also mention our pleasure at seeing here the Master of another of the City Companies, Mr. Caröe, the Master of the Plumbers' Company. His connection with the work of the Institute of Metals is perfectly obvious in that case. As regards Mr. Leslie Robertson, I could say a good many things, and as he is a safe distance away I might be fairly safe in saying them. Mr. Robertson is essentially a fighting man. I had the pleasure of being associated with him in a certain visit to America in 1912, where I saw Mr. Robertson almost single-handed stem the tide of America's efforts to interfere with international specifications. I remember a very distinguished American metallurgist—I will call him Professor " Y "—who, after a long discussion of that kind came to me mopping his brow, saying, "Is not there any way of inducing Mr. Robertson to change his mind ? " I said, " Well, Professor, if it is a matter of suggesting that anything can be better than British Engineering Standard Specifications, I am quite sure you will never get him to change his mind." Now, Mr. Robertson, being that sort of man, I do not think I will say anything more about him ; it will be safer not to. I will ask you simply to join with me in drinking the health of " Our Guests," coupled with the names of Sir Frederick Donaldson and Mr. Leslie Robertson.

Sir H. FREDERICK DONALDSON (Chief Superintendent, Royal Ordnance Factory ; President, the Institution of Mechanical Engineers), in reply, said : The joy of a host is, I understand, always in the appreciation of his guests. I can assure you to-night that that appreciation goes out to you in no stint. On behalf of my share of the guests and myself, I congratulate your Institute most cordially on what you have done in the past, and I express the hope that you may go on and prosper in the future.

Mr. LESLIE S. ROBERTSON (Secretary, the Engineering Standards Committee), in responding, said : I do not know why there has been placed upon me the honour of replying for the guests, except perhaps it be on the principle of the youngest member of the House of Commons moving the address. The Engineering Standards Committee is a com-

paratively young body, and is only a very little older than the Institute over which you have the honour to preside. We started with one small Committee. It is interesting at this date to look back. The Standards Committee is essentially a British institution. We started with six members ; I will not mention the names here, but they would be honoured names in any gathering of British engineers. We have grown steadily from six members serving on one Committee to over sixty Committees doing nothing but standardization work, with, I think, about six hundred of the leading engineers, chemists, specialists, and Government representatives serving thereon. We have spent over £40,000 or more on this particular work. It is, I think, an illustration of where our British methods, though perhaps not quite so scientific or not quite so elaborate as those of our colleagues on the Continent, do fill the function for which they were brought into being. I will venture, even at this late hour, to illustrate where our British methods are perhaps of use. It has nothing to do with the matter referred to by Dr. Rosenhain. It happened at a capital not far from here, where the *entente cordiale* is not unknown.

The British delegates had been fighting an uphill battle with our American and continental friends. After we had finished the first Conference an American representative came to me and said, "Mr. Robertson, I don't know whether you will shake hands with me?" I replied that as far as I was concerned I should be delighted. After we had finished the fourth Conference he came up to me and he said, "Well, Mr. Robertson, I would like to shake hands with you." I asked why? "Well," he said, "I have met a good many men in my life, but I do not know that I have met a harder fighter than you ; but I want to say this, you always fight dead square." Now, gentlemen, if we as Britishers can carry that reputation with us in our international relations, whether we are metallurgists or whatever we are, we need not fear for the old country either in science or in commerce.

OBITUARY.

Robert Kaye Gray died at Brighton, after a long illness, on April 28, 1914. He was born in 1851, and received his early education at Greenock, afterwards studying at University College School, and later at University College, which he left in 1869 in order to study in Paris. During the Franco-Prussian war he was engaged, together with his father, the late Mr. Matthew Gray, in laying a submarine cable from Gravelines to Bordeaux, and from that time on was engaged in laying undertakings in various parts of the world on behalf of his company, the India-Rubber, Gutta-Percha, and Telegraph Works Company, Limited. Of this company Mr. R. Kaye Gray was appointed Managing Director upon the death of his father, retiring in 1913 from this position after being associated with the company for forty-four years. As a result of his arduous cable-laying experiences, which brought him in close touch with the Spanish and Portuguese Governments, Mr. Gray was decorated with several orders by these Governments. Mr. Gray was a notable President of the Institution of Electrical Engineers, over which body he presided in 1903–4. He was a Member of the Council of the Royal Society of Arts, and of many other societies. His connection with the Institute of Metals, of which he was elected a Vice-President a few weeks before his lamented death, dated from the foundation of the Institute in 1908, when he became one of the original Members of Council. In addition, Mr. R. Kaye Gray did very useful work upon several of the Institute's Committees, including the Publication Committee.

William Henry Johnson died at his residence, Woodleigh, Altrincham, on February 19, 1914, in his 65th year.

Than Mr. Johnson there was no one more closely connected with the Institute of Metals, of which he was a founder member and a Vice-President. It was in the Manchester offices of his firm, Messrs. Richard Johnson, Clapham & Morris, Limited, of which he was managing director, that, in February 1908, there was held a meeting of copper manufacturers, brassfounders, shipbuilders, engineers, and others interested in non-ferrous metallurgy, at which it was resolved to take the necessary steps to form a "Copper and Brass Institute." After several further meetings, convened jointly by Mr. Johnson and Professor Carpenter, acting as Honorary Secretaries of the embryo Institute, it was realized that the scope of the institute should not be limited to copper and brass. Hence, it was formally resolved at a meeting held in June 1908, at the Institution of Mechanical Engineers, London, under the chairmanship of the late Sir William White, that an institute, to be called the Institute of Metals, be formed.

Since that time up to a few weeks before his death Mr. Johnson was actively concerned with the welfare and progress of the Institute, and his loss is sadly felt by his colleagues. Apart from his close connection

with the Institute of Metals, Mr. Johnson had many other interests. Thus he was a governor of the Manchester Grammar School, and president of the Mill Girls' Institute, Ancoats. It was chiefly due to his influence and to his desire for better surroundings for his workpeople, that his firm in 1902 established a large new works at Newton Heath. At the same time he privately purchased eight acres of land as a recreation ground for the workers.

He was a generous supporter of Captain Scott's expedition to the South Pole, and entertained the explorer at Woodleigh. Among the few hobbies he permitted himself were yachting and gardening. He was for over forty years a member of the Manchester Literary and Philosophical Society, to which, in earlier years, he contributed papers.

Mr. Johnson was educated in Germany and at University College, London, where he took a first-class honours degree in science. Afterwards he joined his uncle, Mr. Richard Johnson, with whom his father, Mr. William Johnson, of Bowdon, had been in partnership, and later entered the firm of which he became the head and which he served so well for nearly half a century.

WILLIAM GEORGE KIRKALDY died April 10, 1914. Mr. Kirkaldy was born in Glasgow on July 6, 1862, being the son of the late David Kirkaldy. He was educated at University College School, and entered into partnership with his father on coming of age, forming the firm, David Kirkaldy & Son. In addition to his membership of the Institute of Metals, to which he was elected in 1913, Mr. Kirkaldy was an Associate Member of the Institution of Civil Engineers, a Member of the Iron and Steel Institute, the Royal Institution, the International Association for the Testing of Materials, the Royal Society of Arts, the Concrete Institute, and the Court of the Worshipful Company of Turners. He was awarded the Telford Premium by the Institution of Civil Engineers for his paper on "Steel Rails," read before the Institution in conjunction with the late Sir William Roberts-Austen.

ERWIN STARR SPERRY died on January 31, 1914, at his residence in Bridgeport, Connecticut, U.S.A. Born in Ansonia, Conn., on February 28, 1866, he received his education at the Ansonia and Derby High Schools, graduating from the latter in 1884. Subsequently he attended the Sheffield Scientific School of the Yale University, from which he graduated in 1887. He became Assistant Instructor in Chemistry at the Yale University under Professor H. L. Wells, and in 1891 accepted the position of chemist to the Aluminium, Brass, and Bronze Company, Bridgeport. He afterwards became superintendent of the Waldo Foundry.

It was in 1905 that he founded the *Brass World and Plater's Guide*, which he so ably edited till the time of his death.

Mr. Sperry was a member of many scientific societies, both of Europe and the United States, and contributed many valuable papers to their transactions. He was elected a member of the Institute of Metals in 1910.

SECTION II.

ABSTRACTS OF PAPERS

RELATING TO THE NON-FERROUS METALS AND THE INDUSTRIES CONNECTED THEREWITH.

CONTENTS.

THE PROPERTIES OF METALS AND ALLOYS.

CONTENTS.

I.—*COMMON METALS.*

Condensation of Zinc Vapour.—The condensation of zinc vapour to liquid metal is dealt with by F. L. Clere.* The problem is a difficult one, more or less of the zinc being always obtained in the form of a powder, partially oxidized, and known technically as " blue powder." The term is very indefinite, and it is important that there should be a more exact classification of the different products.

The various causes, both chemical and physical, which may contribute to the formation of zinc dust are discussed. The chief chemical cause assigned for the formation of blue powder is oxidation, but the fact that the amount of oxide varies considerably in different samples and that the dust has been successfully melted under conditions in which any reduction of zinc oxide present is unlikely, goes to prove that causes other than oxidation must contribute to the formation of the powder.

It is suggested that in the presence of a certain amount of zinc oxide there may be an upper limit to the size of the globules of zinc which can coalesce with one another, for the reason that while the oxide present may be just sufficient to form a protective coating over each of a number of comparatively large globules, it will be unable to do so in the case of an equivalent weight of smaller globules, owing to the increased surface area.

Gravity and mass action are considered as the extraneous forces which act on the zinc globules and accompanying gas, bringing the molecules sufficiently close together for ultramolecular forces to come into play. In designing a condenser we can extend indefinitely the time

* *Metallurgical and Chemical Engineering*, 1913, vol. xi. (No. 11), pp. 637–640.

during which condensation is possible, and thus allow time enough for gravity to perform the same work in a large condenser which it performs in the Belgian condenser. The importance of a uniform current of gas in a direction favourable to bringing the globules within the range of action of molecular forces is evident, and whatever the rate of evolution of zinc vapour the condenser may have a cross section sufficient to give a proper velocity and direction to the vapour. A suggested design for such a condenser is given.—S. L. A.

Nickel Plating Aluminium.—A process is described by F. Canac and E. Tassilly * consisting in cleaning the aluminium in a boiling solution of potash, etching with hydrochloric acid containing iron, and plating electrolytically in a bath of nickel chloride. The coating may be polished, and is remarkably adherent, standing hammering or bending without cracking. It does not separate below the melting-point of aluminium. The presence of iron in the acid bath is necessary, but its mode of action is uncertain. Iron is completely absent from the deposit.—C. H. D.

Production of Flat Perforated Copper Tubing.—Flat perforated copper tubing for radiators is now manufactured by an electrolytic process by the Electrolytic Products Company, of New Jersey.†

A flat lead strip of approximately $\frac{1}{8}$-inch thickness and perforated at intervals with $\frac{1}{4}$-inch holes staggered with reference to each other, is electroplated with copper and cut into suitable lengths.

These are heated above the melting-point of lead, the lead core being thereby removed, leaving the copper plating in the form of a light copper tubing of an internal contour corresponding to the original perforated lead strip. The distance between the two parallel flat surfaces of copper is equal to the thickness of the lead strip used, and where there were holes in the latter there are now little copper cylinders holding the two flat sides of the copper tubing together. The process is continuous and automatic, the lead passing in form of a long strip through the plating bath. The speed with which it passes through the bath is adjusted to give the requisite thickness of copper required.—S. L. A.

Recrystallization of Hard Zinc.—The changes in structure of hard worked zinc on annealing are discussed by G. Timofeeff.‡

The etching of the samples was effected with a mixture of 94 per cent. nitric acid and 6 per cent. chromic acid; this mixture was diluted to the extent of a few drops in 100 cubic centimetres of water before use.

The microstructure of the cast metal consists of comparatively large grains, often showing a cross-hatching upon their surfaces, presenting a structure analogous to that of martensitic steel.

Cast specimens of zinc were prepared and strained in compression.

* *Comptes Rendus*, 1914, vol. clviii. p. 119.
† *Metallurgical and Chemical Engineering*, 1914, vol. xii. (No. 1), pp. 67–68.
‡ *Revue de Métallurgie*, 1914, No. I., p. 127.

As it was found that a very slight rise in temperature effected a noticeable change in the microstructure of the strained metal, the specimens were cooled with ice during the compression and subsequent polishing operations. The strained specimens were then annealed at different temperatures over boiling alcohol (65° C.), water (100° C.), naphthalene (208° C.), diphenylamine (302° C.), and mercury (360° C.). The microphotographs show that the average size of the crystal grain in the annealed specimens increases uniformly with the annealing temperature, the hardness suffering a corresponding decrease in value, until it finally reaches the same figure as that found for the cast metal. It was found in all cases that the size of the grains was greater at the edges than in the middle of the specimen; this is ascribed to the greater amount of plastic strain at the edges of the specimens during deformation by compression.

The author obtained acicular structures similar to those noted above in the cast specimens, on subjecting soft annealed zinc to a slight shock. He considers that this phenomenon is due to a development of the crystalline planes of slip, caused, in the case of the cast metal, by knocking or jarring in stripping the ingot. It is concluded that the velocity of recrystallization depends both upon the temperature of annealing and upon the severity of plastic strain; the final size of the crystalline grains when annealing at a given temperature is limited by the duration of heating. The paper is illustrated by a number of interesting micrographs, but the magnification of these is not stated.—D. E.

Refining Copper with Magnesium.—It is stated * that magnesium may be employed for removing the last traces of oxygen from copper which has previously been partly refined in the usual manner. Excess of magnesium over the quantity necessary to combine with the residual oxygen must be avoided, as it would deteriorate the copper. The copper should be covered with acid slag or a boric acid flux, with which the magnesium oxide will combine.—D. E.

Resistivity of Copper from 20° to 1450° C.—The resistivity-temperature relationship for copper has been investigated by E. F. Northrup † between 20° and 1450° C. The measurements were made by a potential method using a Kelvin double bridge.

The apparatus, which is fully described, consists essentially of a U-tube made by drilling $\frac{1}{4}$-inch holes in a compressed but undried block, made of a mixture of equal parts of magnesite cement and alundum cement, supplied by the Norton Company of Worcester, Massachusetts. After drilling, the block was dried and baked thoroughly at 1400° to 1500° C. The block containing the U-tube also carries a hole for the thermocouple, and a central riser through which additional metal can be added if necessary. Two side limbs were also drilled out of the block to accommodate the potential leads. The current and potential electrodes

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* *Brass World*, 1913, vol. ix. p. 386.
† *Journal of the Franklin Institute*, 1914, vol. clxxvii. p. 1.

were of molybdenum wire; it is claimed that this metal will not alloy with copper, and so contamination of the melt is avoided. Oxidation of the copper at the high temperatures of these experiments was avoided by working in an atmosphere of carbon monoxide which was maintained automatically by the furnace heater itself.

The furnace was of tubular form 30 cm. in length, and it is stated that it was capable of melting platinum without suffering thereby, but details of its construction are not given in the present paper. No figures relating to variations of temperature in the furnace are given; it is to be noted that, as the distance between the potential points was only 7 cm., the temperature should be fairly constant over this length in a furnace 30 cm. in length.

The U-tube vessel was calibrated with mercury, so that results obtained with the copper could be converted into absolute reading of resistivity. The copper used in the experiments was of two kinds, having respectively a conductivity of 99·71 per cent. and 99·39 per cent. of the Matthiessen standard.

Experiments were made both with rising and falling temperature, and the rate of heating or cooling was such that a series of observations from 1450° to 20° C. was obtained in from six to ten hours.

The resistivities found were:—

Temperature. (Degrees C.)	Resistivity. (Michroms per cm. cube.)
20	1·7347
1082	10·20 (metal solid)
1082	21·30 (metal liquid)
1450	24·22

The results are given in tables and curves; the latter are of the typical form, showing two inflexions occurring respectively at the beginning and end of the freezing.—D. E.

II.—*RARE METALS*.

Hydrocyanic Acid as a Solvent for Gold.—H. T. Lambert * gives the results of experiments made in order to determine the volatility of hydrocyanic acid in solution and the action of such a solution on gold. A curve is given, showing the rate of volatilization from a solution, the original strength of which was in terms of KCN 0·28 per cent.; volatilization was complete in $16\frac{1}{2}$ hours, the average atmospheric temperature being 22° C. All tests for HCN were made by adding to the solution an excess of potassium hydrate and titrating with silver nitrate, using potassium iodide as an indicator.

In Table I. are given the results of experiments to determine the solubility of gold leaf floated on solutions of HCN and KCN.

In Table II. are given the results of other experiments in which a comparison was made of the solubilities of gold leaf in (1) a solution of

* *The Mining Magazine*, 1914, vol. x. p. 138.

KCN "neutralized" with sulphuric acid, using phenolphthalein as an indicator; (2) a similar solution with twice the quantity of sulphuric acid required for (1).

The inference that gold was soluble in (1) because of the absence of alkaline cyanide was incorrect, since it was found that KCN existed to the extent of 0·016 per cent., although showing no alkaline reaction in the presence of a much greater quantity of HCN. In the course of time the solution becomes alkaline on account of loss of HCN by volatilization. There was no free alkaline cyanide present in (2).

Further experiments on a gold ore gave the following results :—

(1) In solution of KCN 66·4 per cent. of the gold dissolved.

(2) In similar solution "neutralized" with sulphuric acid 30·2 per cent. of the gold dissolved.

(3) In solution of HCN no gold dissolved.

The ore, ground to pass 150 mesh, was agitated for 10 hours in an experimental Pachuca vat; the original strength of the solution in each case (in terms of KCN) was 0·25 per cent.; the gold content of the ore was 13·6 dwts.

Table I.

HCN in terms of KCN.	Time.	KCN.	Time required to dissolve Gold Leaf.
0·316 per cent.	No perceptible difference in leaf after twenty hours.	0·316 per cent.	3·5 minutes
0·030　,,		0·030　,,	13·5　,,

Table II.

No.	Time required to dissolve Gold Leaf.	Remarks.
1	Thirty-five minutes.	Strength of KCN before adding acid, 0·66 per cent.
2	No perceptible dissolution after twenty hours.	

—F. J.

Method of making Tungsten Filaments.—Particulars of the process of squirting tungsten filaments for lamps are given from the recent patent of C. A. Hansen.*

A mixture consisting of

Tungsten trioxide	39·8 parts
Glucose	1·2　,,
Starch	1·0　,,
Glycerine	3·0　,,

is made up and squirted through a die of the required size. The plastic thread obtained is wound upon a form to support it, and is dried in an ordinary muffle furnace at 150° C. for ten minutes. The filament is next carbonized in a muffle at 300° C., and is finally placed in a graphite crucible and fired in an electrical resistance furnace working in an atmosphere of hydrogen at a pressure of about 20 mm. of mercury.

The above particulars may be of interest as providing a possible method of winding tungsten resistors for electric furnace heating to high temperatures.—D. E.

Particulars of a patent for making ductile tungsten are given.* The patent was granted on Dec. 30, 1913, to Dr. W. D. Coolidge of Schenectady, N.Y., and assigned to the General Electric Company, U.S.A. It relates to "Tungsten and methods of making the same for Use as Filaments of Incandescent Lamps and Other purposes." A few of the thirty-four claims in the patent are quoted.—S. L. A.

Preparation of Rare Metals.—An improvement in the preparation of some of the rare metals is described by M. Billy.† This consists in heating the chloride of the metal with sodium hydride. The vapour of the chloride is passed, mixed with hydrogen, over porcelain boats containing globules of sodium, supported on a layer of sodium chloride, these boats being heated to 400° to 420° C. Hydrogen is passed first alone, to convert the surface of the sodium into hydride. Pure titanium is readily obtained in this way:

$$TiCl_4 + 4NaH = Ti + 4NaCl + 2H$$
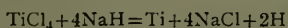
and is of a high degree of purity.—C. H. D.

III.—*ALLOYS*.

Alloy for Edge Tools.—Some of the properties of nickel-chromium, cobalt-chromium, and stellite alloys are given by E. Haynes,‡ who has aimed at producing an alloy which would take a good cutting edge, and at the same time resist atmospheric influences so as to retain its lustre.

A nickel-chromium alloy, produced by the reduction of the combined oxides by means of aluminium, could be readily filed, but was practically immune from atmospheric influences and insoluble in nitric acid.

Similarly produced alloys of cobalt and chromium were very hard and tough, and possessed a fine lustre when polished. They were unaffected by atmospheric influences, and were insoluble in nitric acid.

Produced on a large scale, and kept from contamination with carbon, cast bars could be forged, with care. Table knives, pocket knives, and other cutlery made from the forged bars retained their lustre under all sorts of exposure.

* *Metallurgical and Chemical Engineering*, 1914, vol. xii. (No. 11), p. 108.
† *Comptes Rendus*, 1914, vol. clviii. p. 578.
‡ *The Iron Trade Review*, 1914, vol. liv. p. 468.

Small quantities of carbon, tungsten, molybdenum, &c., were added to these alloys with a view to increase their hardness and elasticity to such an extent as to render them serviceable for cutting other metals.

It required 10 per cent. tungsten to obtain a decided increase in hardness and density. An alloy containing 20 per cent. tungsten could be forged to a slight extent, and showed fairly good cutting qualities as a lathe tool. With 40 per cent. tungsten the alloy was hard and brittle (percentages of cobalt and chromium are not given).

Molybdenum acted similarly to tungsten, but was more intense in its action. An alloy consisting of 25 per cent. chromium, 65 per cent. cobalt, and 10 per cent. molybdenum makes an excellent lathe tool. The alloys are being improved from time to time.

The properties of " stellite " are considered.

Upon being heated no change takes place in the colour and brightness of stellite until a temperature of 800° F. has been reached. Colour films then appear similar to those occurring on polished steel, but at higher temperatures. After cooling the alloy assumes its former hardness, the cutting edge of a stellite tool being retained both at a red heat and after cooling down from a red heat.

The following cutting tests have been reported by a manufacturer :—

	Feet per Minute.
Superior high-speed steel on phosphor bronze	125
Stellite on phosphor bronze	900
High-speed steel on tool steel	80
Stellite on tool steel	133
Steel on seamless tubing	100
Stellite on seamless tubing	400
Steel on cast iron	100
Stellite on cast iron	200

It is stated that it is not advantageous to work a tool regularly at such high speeds as those given above, but that a stellite tool will remove metal under a given depth of cut fully twice as fast as a steel tool under the same conditions.

It is to be regretted that fuller information regarding the compositions of the stellite and steel tools above mentioned is not forthcoming.—F. J.

Aluminium Alloy.—An aluminium alloy capable of being rolled into thin sheets or otherwise manipulated as a malleable metal has been patented by W. A. M'Adams.* It contains aluminium, zinc, and copper in such proportions that the aluminium will be substantially five times by weight the amount of zinc, and the zinc substantially five times by weight the amount of copper.—S. L. A.

Aluminium and Tin Alloys.—This series has been once more examined by R. Lorenz and D. Plumbridge.† These authors find a complete absence of solid solutions, and fix the eutectic point at 98 atomic per cent. of tin, confirming Gwyer's results, and disproving the assumption of some previous authors that compounds are formed.—C. H. D.

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* *Metallurgical and Chemical Engineering*, 1913, vol. xii. (No. 11), p. 658.
† *Zeitschrift für anorganische Chemie*, 1913, vol. lxxxiii. p. 243.

Bismuth, Cadmium, and Zinc Alloys.—This ternary system has been investigated by C. H. Mathewson and W. M. Scott,* who find that there is less difficulty in determining the composition of the conjugate liquid phases than has been often supposed. Solid solutions are formed to such a small extent that they may be neglected. The equilibrium is discussed from the standpoint of the thermo-dynamical potential, but the experimental results are presented in the usual form, by constructing a number of vertical sections through the space-model, about a hundred alloys being examined thermally.

Addition of cadmium to alloys of zinc and bismuth lowers the temperature at which two liquid layers are in equilibrium with solid zinc. The critical point at which the two liquids coalesce in presence of solid zinc is at 326° C., and lies at 6·9 atomic per cent. of bismuth, 47·1 per cent. cadmium, and 46·0 per cent. zinc. The critical curve is highly unsymmetrical. The ternary eutectic point is at 143° C., only 2° below the bismuth-cadmium eutectic temperature. The ternary eutectic contains 44·3 atomic per cent. of bismuth, 54·1 per cent. cadmium, and 1·6 per cent. zinc.—C. H. D.

Bismuth and Thallium Alloys.—Somewhat remarkable conclusions are reached by N. S. Kurnakoff, S. F. Schemtschuschny and V. Tararin.† The freezing-point curve of the system has three maxima. One occurs at 0·9 atomic per cent. of bismuth and 301·5° C., the second at 12·03 per cent. and 303·7° C., and the third at 62·8 per cent. and 214·4° C. All three correspond with the formation of solid solutions, but the range of the third series is very restricted. The electrical conductivity curve has a sharp, upward-directed cusp at 64 atomic per cent., and the limits of the solid solutions are fairly distinctly marked. The temperature-coefficient curve has an abrupt change of direction at the same point. The position of these points does not correspond with a simple formula, such as that of Bi_5Tl_3, assumed by other investigators.

The hardness was determined in three ways: by Brinell's ball test, by Ludwik's sclerometric method, and by measuring the pressure required to produce flow through an orifice. All three methods give curves of identical form. The limits of solid solution are very clearly indicated, and the authors consider that the curves do not afford any evidence for the existence of a compound Bi_5Tl_3. The microstructure is that which would be expected from the thermal diagram.

The authors draw the conclusion that the phase formerly regarded as Bi_5Tl_3 is a "compound of variable composition," of the kind formerly assumed to exist by Berthollet, and that the singular points in the curves of physical properties cannot therefore be expected to correspond with rational formulæ. This conclusion, which is unlikely to secure general acceptance, is extended by them to the β, γ, δ alloys, &c., of copper with zinc and other metals.—C. H. D.

* *International Journal of Metallography*, 1913, vol. v. p. 1.
† *Zeitschrift für anorganische Chemie*, 1913, vol. lxxxiii. p. 200.

Brass.—In a general article on brass, O. Weber * gives the composition of alloys used in the jewellery trade for imitation gold as 96 : 4 (red gold) and 85 : 18 (yellow), for rolled sheet 89 : 10 : 1 (red gold) 82 : 17·5 : 0·5 (yellow). In each case the first metal is copper, the second zinc, and the third tin. " English gold " is either 94 : 6 or 89 : 11.

Brass taps have the composition copper 83 to 85, zinc 10, tin 3, and lead 4 per cent. on the average.—C. H. D.

Cerium Alloys with Silicon and Bismuth.—Cerium is found by R. Vogel † to combine violently with silicon and bismuth at high temperatures. It appears to form a single silicide, melting at about 1530° C., with a eutectic point near to 1250° C. Solid solutions are not formed. Alloys containing the compound are brittle, rather softer than silicon, stable in air, and not pyrophoric. The alloys with bismuth are complex. The compound Bi_3Ce_4 melts at 1640° C. far above either of its components, and other compounds $BiCe_3$, $BiCe$, and Bi_2Ce, are considered to be indicated by breaks in the freezing-point curve, but the number of points is small. The alloys oxidize very readily, being reduced to a black powder in air in a few seconds. Between 25 and 75 per cent. of bismuth the alloys may even be set on fire by contact with water.—C. H. D.

Copper, Nickel, and Aluminium Alloys.—These alloys have been examined mechanically and microscopically by L. Guillet.‡ Three series of alloys were used, containing 60, 83, and 90 per cent. of copper respectively, the aluminium varying from 0 to 9·7 per cent., with 0·2 to 0·8 per cent. of iron. A small addition of aluminium greatly improves the properties of the alloys, probably by acting as a deoxidizer. The breaking load and hardness increase rapidly with increasing percentage of aluminium, then pass through a maximum and decrease, the maximum is higher the lower the copper content, and corresponds with a higher aluminium percentage the higher the copper content. With the more brittle alloys, the breaking load and hardness test do not always give concordant results. Some of the cast alloys have a tenacity of 70 to 75 kilogrammes, but the ductility is then very small.

The microscopic structure is exactly the same as that of the binary alloys of copper and aluminium containing the same percentage of aluminium—that is, the nickel simply replaces copper. Quenching is without effect on the solid solutions, but alters those alloys which contain the β constituent.

The alloy containing 82·2 per cent. copper, 14·98 per cent. nickel, 2·50 per cent. aluminium, 0·23 per cent. zinc, and 0·06 per cent. lead, is greatly improved by forging, both the elongation and the hardness being increased.—C. H. D.

* *Elektrochemische Zeitschrift*, 1913, vol. xx. p. 53.
† *Zeitschrift für anorganische Chemie*, 1913, vol. lxxxiv. p. 323.
‡ *Comptes Rendus*, 1914, vol. clviii. p. 704.

Gold and Arsenic.—These alloys, as far as 25 atomic per cent. of arsenic, have been examined by A. P. Schleicher.[*] Arsenic enters only to an inappreciable extent into solid solution, and the eutectic arrest is well marked. It is characteristic of these alloys that on cooling, evolution of arsenic vapour takes place suddenly at the eutectic temperature.—C. H. D.

Gold, Copper, and Nickel.—These ternary alloys have been examined by P. de Cesaris.[†] Nickel and gold form an eutectic, whilst the other two pairs of metals form solid solutions. The greater part of the system is occupied by ternary solid solutions, with a gap in alloys containing less than 15 per cent. of copper. It is difficult to attain a state of equilibrium during cooling.—C. H. D.

Improvement of Aluminium.—The use of cobalt is recommended [‡] for improving the quality of aluminium. With 9 to 12 per cent. of cobalt the castings are free from porosity and are harder, more easily worked, and more resistant to corrosion than pure aluminium. The tensile strength is low, on account of the very coarsely crystalline structure. This may be made finer by the addition of tungsten or molybdenum. With 9 to 10 per cent. of cobalt and 0·8 to 1·2 per cent. of tungsten, or 0·6 to 1·0 per cent. of molybdenum, alloys are obtained with three times the tensile strength of aluminium and good forging and rolling properties. The molybdenum alloys are softer than those containing tungsten. Of the above alloys, those richest in cobalt are only suitable for casting purposes, the lower cobalt content being suitable for rolling.

Another paper [§] describes the alloys of aluminium used in the motor industry, &c. The alloy containing 87 per cent. of aluminium, 8 of copper, and 5 of tin is preferable to those which contain zinc, on account of both casting and working properties. Duralumin contains 5 per cent. of copper, 0·25 to 0·5 of magnesium, and 0·5 to 0·8 of manganese.—C. H. D.

Light Aluminium Alloys.—It is stated [||] that the study of these alloys has made considerable progress during the last few years, valuable contributions to our knowledge on the subject having been made by MM. Guillet and Portevin in France, and by Messrs. Rosenhain and Archbutt in England, whose researches have brought out several important facts.

The purity of the constituent metals has considerable influence upon the mechanical properties and corrodibility of the alloys. Rosenhain attributes the corrodibility of certain commercial aluminium-zinc alloys to the presence of impurities derived from the zinc used.

[*] *International Journal of Metallography*, 1914, vol. vi. p. 18.
[†] *Gazzetta Chimica Italiana*, 1914, vol. xliv. i. p. 27.
[‡] *Elektrochemische Zeitschrift*, 1914, vol. xx. p. 295.
[§] *Ibid.*, p. 264.
[||] *Métaux et Alliages*, 1914, No. IV., vol. vii. p. 5.

As already noted in this Journal,* the aluminium and zinc used were the purest available (99·63 per cent. aluminium and 99·98 per cent. zinc).

With the addition of zinc to aluminium an improvement in mechanical properties follows, rising gradually up to a maximum at 30 per cent. zinc. No " ageing " influence was noticeable on these alloys.

It is suggested that the results of research on the binary alloys will lead to the elucidation of numerous anomalies in connection with ternary and quaternary alloys. A study of the equilibrium diagrams, the formation of solid solutions and their limits of solubility, as also a consideration of electrical conductivities, should do much towards defining the spheres of usefulness of such alloys.

The most complete studies hitherto have been made of simple alloys, *e.g.* aluminium-copper, aluminium-zinc-copper, and aluminium-copper-manganese; whilst less complete studies have been made of alloys of aluminium containing magnesium, nickel, and iron.

In the aluminium-zinc alloys a useful series of solid solutions exists from 0 to 30 per cent. zinc. Homogeneity is only obtained (and consequently high mechanical resistance) by slow cooling, reheating, or hot-working accompanied by reheating.

For some alloys rich in zinc four thermal transformations occur, as shown by the cooling curves, two of which are important, viz. that at 443° C. (formation of a definite compound containing 78·3 per cent. zinc), and that at 256° C. (solidification of eutectic containing 95 per cent. zinc). (The writer of the article has given the wrong temperature for the freezing of the eutectic, which takes place at a higher temperature, viz. 380° C.; the temperature of 256° C. represents the decomposition of the component Al_2Zn_3 formed at 443° C.)

With alloys of less than 30 per cent. zinc no such transformations are to be feared, and the hope is expressed that with light alloys the endeavour to obtain homogeneity by heat treatment will not be attended by a deterioration of their useful properties. By attaining chemical and physical equilibrium corrodibility is decreased, consequently castings should be annealed.

Rapid cooling, and drawing or working cold, should be avoided.

The tenacities of sand and chill castings are compared, and it is shown that two maxima exist: in the case of sand castings, viz. at 50 per cent. zinc and 75 per cent. zinc, which maxima exist in the case of chill castings, in addition to one at 30 per cent. zinc.

The variations up to a composition of 25 per cent. zinc are very similar in sand and chill castings, the values in the latter being slightly higher.

The utilization of these alloys in the automobile industry, aviation, and in all general uses where a combination of lightness and high tenacity is considered in connection with the specific tenacity.† The specific tenacity of aluminium-zinc alloys increases regularly up to a

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* *Métaux et Alliages*, 1913, No. I., vol. ix. p. 214.
† This term is defined by Rosenhain in his Report to the Alloys Research Committee. See abstract, this Journal, 1913, No. 1, vol. ix. p. 214.

maximum at 25 per cent. zinc, decreases slightly, to rise again to a new maximum at 40 per cent. with sand castings and 50 per cent. with chill castings, and decreases with higher percentages of zinc.

Alloys containing 25 per cent. zinc present the best combination of tenacity and specific lightness. Similar considerations have led to the adoption of manganese-copper-aluminium alloys containing 3 per cent. copper and 1 per cent. manganese. A comparison of three light alloys, both in the sand-cast and chill-cast condition, is given.

Chill Castings.

Percentage of Zinc.	Tenacity Kilos. per Square Millimetre.	Elongation.	Specific Gravity.	Specific Tenacity.
15	18·42	8·5	2·956	6·24
19	21·58	7·0	3·06	7·06
26	27·91	4·0	3·21	8·75

Sand Castings.

15	17·95	2·0	2·956	6·07
19	20·91	2·5	3·0	7·00
26	23·85	2·2	3·17	7·5

The alloys containing from 10 to 30 per cent. zinc can be machined without lubrication.

They can be varnished, but only with carbonaceous or bituminous varnishes. Varnishes with salts of lead as a base are very bad, as also are metallic varnishes, as the oxides of their metals intensify electrochemical corrosion.

The mechanical properties of the alloy containing 25 per cent. zinc and 3 per cent. copper in the sand-cast, chill-cast, and roller condition are also quoted.—F. J.

Malleable Zinc Alloy.—An alloy consisting of zinc 99·1 to 99·9, aluminium 0·001 to 0·1, lead up to 0·01 per cent., is claimed to be extremely tough and strong, and is malleable and suitable for stampings. The alloy has been patented by T. A. Bayliss, England.*—S.L. A.

Manganese and Cobalt.—These two metals are found by H. Hiege † to form a continuous series of solid solutions, the freezing-point curve passing through a flat minimum at about 1160° C. The magnetic transformation temperature of cobalt is rapidly depressed by alloying with manganese. The structure shows cores initially, but becomes homogeneous on annealing.—C. H. D.

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* *Metallurgical and Chemical Engineering*, 1913, vol. xi. (No. 12), p. 717.
† *Zeitschrift für anorganische Chemie*, 1913, vol. lxxxiii. p. 253.

Manganese and Silver Alloys.—Contrary to previous investigations, G. Arrivaut * finds that manganese and silver form a compound, Ag_2Mn, which forms solid solutions with silver, and melts at 980° C. With from 20 to 94 per cent. of manganese the alloys separate into two liquid layers, the horizontals of the diagram being at 980° C. and 1148° C. respectively. This is confirmed by microscopical examination. The alloy, rich in manganese, is readily attacked by acids; whilst the compound is very little attacked, and may be isolated in an undecomposed state.

The electromotive-force curve has a sudden break at the composition Ag_2Mn.—C. H. D.

Melting-points of Commercial Brasses and Bronzes.—In connection with an investigation of melting furnaces, Gillett and Norton† have determined the melting-points of a number of commercial copper alloys.

After referring to the previous work of Primrose, Longmuir (who measured temperatures by a method of mixture), and of Karr (using a radiation pyrometer) on the subject, it is concluded that values for the melting-points of commercial copper alloys to an accuracy of within 5° to 10° C. are still lacking.

In their own experiments the authors measured the melting-point, *i.e.* the liquidus point, where the alloys were just completely liquid, by means of a platinum-platinum-rhodium couple adequately protected against contamination in the gas furnace in which the alloys were melted in cylindrical carborundum crucibles. The melt in each case weighed about 600 grammes. The couple was connected through a cold junction, kept at 20° C. ($\pm 3°$), direct to a single-pivot galvanometer.

A number of consecutive heating and cooling curves of each alloy were taken, temperature measurements being made every 15 seconds, stirring the melt between each reading. The results were plotted as time-temperature curves, from which the following melting-points were obtained :—

Alloy.	Composition.				Melting-point.
	Copper.	Zinc.	Tin.	Lead.	Degrees C.
Gun metal * . . .	88·0	2·0	10·0	...	995
Leaded gun metal . .	85·4	1·9	9·7	3·0	980
Red brass * . . .	85·0	5·0	5·0	5·0	970
Low grade red brass .	81·5	10·4	3·1	5·0	980
Bronze with lead * . .	80·0	...	10·0	10·0	945
Bronze with zinc . .	84·6	5·0	10·4	...	980
Half yellow, half red .	75·0	20·0	2·0	3·0	920
Cast yellow brass . .	66·9	30·8	...	2·3	895
Naval brass . . .	61·7	36·5	1·4	...	855
Magazine bronze .	...	...	...	...	870

Alloys marked * were not analysed, but as they contain little or no zinc it is assumed that their compositions approximate closely to the proportions of the various metals added.—C. H. D.

Molybdenum and Cobalt Alloys.—These alloys have been examined by W. Raydt and G. Tammann.* Only a single compound, MoCo, is formed, melting with decomposition at 1484° C. Cobalt can retain up to 28 per cent. of molybdenum in solid solution, and this solid solution is magnetic, the temperature of transformation falling from 1143° C. for pure cobalt to 760° C. at the limit of saturation. The compound is non-magnetic, and does not form solid solutions.

The compound MoCo crystallizes in long needles, and in alloys rich in molybdenum rounded crystals of free molybdenum occur.

Owing to the insolubility of molybdenum in cobalt at 1800° C. only alloys containing up to 65 per cent. have been prepared by direct fusion. Richer alloys, prepared by the aluminothermic process, always contain aluminium.—C. H. D.

Monel Metal.†—Further particulars of the properties and applications of this alloy are given by W. E. Oakley.‡

Difficulties encountered in machining Monel metal are discussed. Tools used for brass turning are unsuitable for work on this alloy, and high-speed steel tools with ample clearance should be used. A diagram is given indicating the manner in which these tools should be ground.

It is claimed that, under the best conditions, a cutting speed of 120 to 140 feet with a quarter-inch cut and a thirty-second-inch feed may be obtained on 5-inch Monel-metal rounds.

The following figures are given for some of the physical properties of the alloy :—

Weight per cubic inch (cast)	0·319 lbs.
,, ,, (rolled)	0·323 ,,
Co-efficient of expansion (20°–100° C.)	0·00001375
Electrical resistivity	20 ohms per mil-foot
	(Temperature co-efficient, 0·0011 per 1° F.)

Mechanical tests on hot-rolled bars gave the following values :—

Yield point	55,587 lbs. per square inch.
Tensile strength	88,232 ,, ,,
Elongation on 2 inches . . .	44 per cent.
Modulus of elasticity	$22 - 23 \times 10^6$.

Torsional Tests.

At elastic limit shearing stress = 31,796 lbs. per square inch.
At ultimate load ,, ,, = 73,053 ,, ,,

The properties of strength and resistance to corrosion at high temperatures, which Monel metal is stated to possess, are quoted as auguries of an extended application of the alloy, and its use for forged turbine-blades is noted in this connection.

It also resists salt water and atmospheric corrosion. Monel metal holders are being employed for the high-tension insulators of the Panama Canal electricity supply.—D. E.

* *Zeitschrift für anorganische Chemie*, 1913, vol. lxxxiii. p. 246.
† See also *Journal of the Institute of Metals*, vol. v. p. 315, vol. vii. p. 279, vol. x. p. 218.
‡ *Metal Industry*, 1914, vol. vi. p. 62.

The recently consolidated Supplee-Biddle Hardware Company, U.S.A., will pay special attention to the many uses of Monel metal.* This "natural alloy," produced by reduction of the Sudbury copper-nickel ores, has an approximate composition of nickel 68, copper 30, iron and manganese together 2, per cent. It has a tensile strength of 70,000 to 100,000 lbs. per square inch, and can be readily machined. Wherever corrosion is a menace Monel metal is proving its superiority. In pump and piston rods, shaftings, valve stems, machine bolts, &c., this alloy outwears bronze by 50 to 100 per cent. During the past year successful forging of Monel metal up to 1000 to 2000 lbs. has been accomplished. Forged valve rings and spindles, seat discs, and rings are now made. Screen wire cloth and ropes of this alloy give maximum service and satisfaction.—S. L. A.

Nickel-Silicon Alloy for Thermocouples.—To avoid brittleness in nickel wire used for thermocouple leads, A. L. Marsh † adds from 3 to 5 per cent. of silicon and a trace of aluminium or manganese to the metal. This alloy has been patented.—D. E.

Nomenclature of Alloys.—Some proposals for a systematic nomenclature are made by W. Guertler,‡ involving the use of contracted names. The name of the metal present in largest proportion comes last. Thus aluminium, with an addition of manganese, becomes mang-al; with magnesium, magnal; with copper, cupral, &c. Certain general names may be employed with restrictions. Thus bronze might be understood to mean a copper alloy containing not more than 30 per cent. of tin. Newly-coined names of this class are to be avoided.

Names are also proposed for micrographic constituents. Thus pure copper would be cuprite; copper with aluminium in solid solution, al-cuprite, &c. Austenite would be γ-carboferrite; and kamacite, α-nickeloferrite. It is proposed to use Roman letters in place of Greek for such solid solutions as those in the alloys of copper and zinc.—C. H. D.

Some light is thrown on the confusion of the terms manganese-brass and manganese-bronze by a summary of the history, manufacture, and properties of these two materials given by W. M. Corse and V. Skillman.§

The addition of small amounts of iron to copper alloys was known to have a decided hardening and strengthening effect. It produced, however, a decreased ductility. The substitution of manganese for iron was tried, and some benefit resulted, due to the deoxidizing action of the manganese. It remained for F. M. Parsons of London to take out a patent in February 1876 for the addition of both iron and manganese. The patents were controlled by the Manganese Brass and Bronze Company of London. The alloys manufactured ranged from those containing zinc

* *Metallurgical and Chemical Engineering*, 1914, vol. xii. (No. 1), pp. 68–69.
† *Brass World*, 1913, vol. ix. p. 388.
‡ *International Journal of Metallography*, 1914, vol. vi. p. 23.
§ *Metallurgical and Chemical Engineering*, 1914, vol. xii. (No. 11), pp. 113–115.

much in excess of tin, to others composed practically of copper and tin only. It was soon discovered, however, that the manganese brasses, or high-zinc alloys, were quite unsuited for sand castings, and they were almost completely discarded for the manganese bronzes, or manganese-tin-copper alloys, and the earlier castings of propellers and the like, described as made of manganese-bronze, were cast from true bronzes. In 1888 Parsons was granted a second British patent covering the addition of aluminium to manganese brasses, thus making it possible to produce sand castings from a cheap brass containing as much as 40 to 45 per cent. zinc, which had physical properties equal or even superior to those made from the more costly bronze. A confusion of terms resulted. The alloy now recognized as manganese-bronze is in reality nothing more than a special high-zinc brass. The presence, however, of the metals other than copper and zinc is what places this highly valuable alloy in a class by itself. At the present time it is the principal non-ferrous alloy used in the form of castings to any extent as a substitute for steel. There are two grades of manganese-brass manufactured, one containing no aluminium, used for rolling and drawing, and the other used for castings in which aluminium is an essential constituent. The U.S. Navy Department Specification calls for manganese-brass containing copper 56 to 58, zinc 40 to 42, tin, aluminium, lead, and manganese not exceeding 1, 0·5, 0·10, and 0·3 per cent. respectively. As regards physical properties, a test specimen properly cast in sand should give well over 70,000 lbs. per square inch tensile strength, and at least 20 per cent. elongation on 2 inches. In making this metal the tin, iron, and manganese are added together in the form of a "hardener" or alloy prepared by melting together 80 per cent.: ferro-manganese 56·3, wrought iron 12·5, and tin 32·1 per cent. The following proportions are then used in making the brass :—

	Per Cent.
Copper	55·0
Zinc	42·0
Hardener	2·5
Aluminium	0·5

A portion of the copper is melted, and after being brought to a good heat the hardening alloy is added. This must be thoroughly stirred in, and heating continued until it is entirely melted and alloyed. The aluminium is then added, which causes a further rise in temperature, thus ensuring the melting of the last traces of the hardener. The remainder of the copper is then added, and finally the zinc, which must be of good quality, as lead is very detrimental to the finished brass.

It is generally conceded by founders that this alloy is one of the most difficult of the non-ferrous mixtures for the uninitiated properly to handle. As a result of the high zinc content, the melting-point is comparatively low, lying between 1400° to 1500° F., and therefore overheating or "burning" easily happens. The approximate production in the United States is 1500 tons annually.—S. L. A.

U

G. K. Burgess * suggests the advisability of a more systematic classification of alloys.

It is not proposed to abolish such time-honoured names as "brass" or "bronze," but misleading terms such as "manganese-bronze," and personal and proprietary names, should be disallowed.

The nomenclature of ferrous alloys—ferro-silicon, ferro-manganese, &c.—is suggested as a basis for a method of nomenclature for the non-ferrous alloys. The present method of naming the microscopical constituents of non-ferrous alloys, according to the usages of physical chemistry, is upheld.

It is urged that, in any revision of nomenclature, regard must be had to the equilibrium diagram, since this is an index of the exact compositions at which well-marked alterations of the properties of alloys may be expected to occur. Co-operation between the various British and American metallurgical societies is suggested with regard to such a revision of nomenclature.

In a paper read before the American Institute of Metals, C. P. Karr † outlines a tentative scheme of nomenclature for non-ferrous alloys, of which the more important items are as follow :—

Bronze.—A copper-tin binary alloy with copper as chief constituent.

Brass.—A copper-zinc binary alloy with copper as chief constituent.

Composition.—An alloy of two or more metals with copper as chief constituent.

    (*a*) Bronze composition such as copper 89, tin 10, lead 1.
    (*b*) Brass composition such as copper 70, zinc 29, lead 1.
    Lead composition, aluminium composition, &c.

White Metal Alloy.—A binary alloy of any two white metals.

White Metal Composition.—A binary alloy of two white metals containing variable minor components, *e.g.* fusible metal or pewter.

Anti-friction and Bearing Metals.—Are either

    (*a*) White metal alloys or compositions.
    (*b*) Brasses or brass compositions.
    (*c*) Bronzes or bronze compositions.

Amalgams.—Alloys of mercury with various metals.

Noble Metal Alloys.—Binary combinations of noble metals.

Binary Alloys.—Exclusive of brass or bronze (and white metals ?) are placed in a class by themselves, the chief constituents forming the qualifying title, *e.g.* cupro-nickel.

The retention is suggested of such trade names as Delta metal, Muntz metal, &c., which are held not to interfere with the scheme outlined above. The paper concludes with some examples, the present names, composition, and proposed designation of a number of alloys being given.—D. E.

* *Metal Industry*, 1913, vol. v. p. 487.   † *Ibid.*, vol. vi. p. 15.

Palladium and Nickel Alloys.—According to F. Heinrich [*] palladium and nickel form a continuous series of solid solutions, the freezing-point curve passing through a minimum at about 1250° C. There is considerable undercooling. All the alloys are more readily attacked by nitric acid than either nickel or palladium. The temperature of the magnetic transformation of nickel is lowered by palladium. The alloys are somewhat malleable, and are not much harder than the component metals.—C. H. D.

Silver and Cuprous Oxide.—It is found by C. H. Mathewson and C. H. Stokesbury [†] that cuprous oxide dissolves readily in molten silver. The alloys are best prepared from cuprous oxide previously purified by melting the commercial preparation under fused sodium sulphate in a magnesia crucible, breaking up the mass, and separating the copper shot. The alloys with silver are also melted under sodium sulphate. Silver and cuprous oxide form a simple binary system, with a eutectic point at 944° and 1·3 per cent. of the oxide. With 12 per cent. of the oxide the freezing-point has risen to 1085° C. Solid solutions are not formed.

The lowering of the freezing-point of silver is greater than that calculated from the latent heat, and points to a reaction :

$$Cu_2O + 2Ag \rightleftarrows 2Cu + Ag_2O.$$
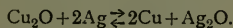
Small quantities of the oxide are not removed by melting the alloy in hydrogen. The microstructure is almost exactly like that of the alloys of copper and cuprous oxide.—C. H. D.

Soldering Fluxes for Soft Solder.—In a paper read before the American Institute of Metals, in October 1913, W. Arthur [‡] describes experiments on various fluxing materials for use in soft soldering.

General considerations point to the desirability of rapid action of the flux, so that it should consist of a liquid or a paste which does not require melting or evaporating before its cleaning action commences.

For soldering tinplate, galvanized iron, copper, or brass, fluxes such as zinc chloride, ammonium chloride, or resin may be employed. Zinc chloride, however, is poisonous and highly corrosive, and so is unsuited for soldering vessels for tinned food, or for use in cases where delicate work is in question, as in the soldering of the thin zinc wires used as electric fuses.

An aqueous solution of ammonium phosphate is recommended for use with tin, copper, brass, and zinc articles. This is non-poisonous and non-corrosive, but requires a high temperature for successful fluxing. Lactic acid and ammonium lactate are said to be useful fluxes, but they produce a tarnish on copper and brass.—D. E.

[*] *Zeitschrift für anorganische Chemie*, 1913, vol. lxxxiii. p. 322.
[†] *International Journal of Metallography*, 1914, vol. v. p. 193.
[‡] *Metal Industry*, 1914, vol. vi. p. 2.

Standard Sheet Brass.—The Bureau of Standards, Washington, is prepared to issue, as an analytical standard, a sheet brass of the following composition approximately : *—

								Per Cent.
Iron .	.	.	.	.	.	.	.	0·3
Nickel	.	.	.	.	.	.	.	0·5
Tin .	.	.	.	.	.	.	.	1·0
Lead	.	.	.	.	.	.	.	1·0
Zinc	.	.	.	.	.	.	.	27·0
Copper	.	.	.	.	.	.	.	70·3

The fee, payable in advance, is 3 dollars per sample of about 150 grammes weight.—S. L. A.

Tin, Zinc, and Cadmium Alloys.—The binary and ternary alloys of these metals have been examined by R. Lorenz and D. Plumbridge.† Tin and zinc form alloys which contain the metals in an almost pure condition, solid solutions being absent. In the alloys of cadmium and zinc the limits of the solid solutions are well below 1 per cent., whilst in the cadmium-tin series they may extend slightly further.

The ternary system is of the simplest possible type, the zinc field being by far the largest on the liquidus surface. The following eutectic points are found :—

	Per Cent.			Degrees C.
Tin-zinc . .	. 13·5	Atomic zinc	. .	. 199
Cadmium-zinc .	. 20	,, ,,	.	. 263
Tin-cadmium .	. 29	,, cadmium	.	. 177
Tin-zinc-cadmium	. 70·83	,, tin .	. .	. ⎫
	3·70	,, zinc	.	. ⎬ 164
	25·41	,, cadmium	.	. ⎭

A thermal effect, due to the tin-cadmium series only, was observed at 120° C.—C. H. D.

Turbine Blade Alloys.—In a note ‡ concerning some of the various materials which have been employed for the manufacture of turbine blades it is pointed out that the desideratum is an alloy which can endure the combination of stress and temperature encountered in turbines running at high speeds under superheated steam.

Ordinary bronzes are unsatisfactory as a blade material, but some special bronzes such as Durana metal and Resistin (a 5 per cent. manganese-bronze) have proved efficient. Aluminium-bronze, however, is unreliable for this purpose. Wrought-iron blades are fitted to the Thyssen and to Melmis and Pfenninger turbines. Mild steel and nickel steel low in carbon have also been recommended. Tests on Monel metal blades are at present in progress : this alloy appears to be malleable and non-corrodible at high temperatures.—D. E.

IV.—*PHYSICAL PROPERTIES*.

Allotropy of Cadmium.—An allotropic change in cadmium has been discovered by E. Cohen and W. D. Helderman.* By heating cadmium in contact with a solution of its sulphate at 70° to 100° C. a small but distinct diminution of density occurs. The actual temperature of transformation is 649° C.— C. H. D.

Cold-working.—A comparison has been made by Hanriot and Lahure † between metals (brass and silver) hardened to different degrees by cold-working, and hardened to the maximum extent and then softened to different degrees by annealing. Comparing together metals from the two series showing equal hardness by the ball test, it is found that the tenacity of those hardened in an ascending series is always less than that of those in the descending series, whilst the ductility is lower and more irregular in the ascending than in the descending series. It is also found that the partly annealed metals are more readily hardened by traction than those of equal initial hardness obtained directly by cold-working. The metals of the descending series anneal much more rapidly than the others.

There is thus a superiority in every respect of the metals which have been partly annealed after cold-working.—C. H. D.

Corrosion of Copper.—Experiments on the effect of annealing on the corrodibility of hard-worked copper are described by T. A. Eastick.‡

Pieces of ordinary sheet copper were prepared in the hard-worked and annealed condition. The " scleroscope " hardness numbers were found to be 44 and 12 respectively. The electrolyte employed was a 10 per cent. solution of sodium chloride at a temperature of 50° C., and the time of immersion in both cases was fifty-six hours.

By electrically connecting a hard sheet to a soft one and immersing them both together in the same bath the loss in weight under the above conditions was found to be 0·60 per cent. from the hard specimen and 0·41 per cent. from the soft one.

By treating two similar hard and soft specimens separately in separate solutions the loss in weight was found to be 0·59 per cent. in the case of the hard specimen, and 0·60 per cent. in the case of the soft specimen.

It is concluded that the hard metal is electro-positive to the softer metal, and the uneven corrosion of copper pipes and plates is thus attributed to lack of thorough and homogeneous annealing of the material. Further experiments on the corrosion of hard copper strip and sheet, which had been annealed locally, are described in support of the above conclusion.

The result of some tests with aerated and boiled solutions indicate that the presence of dissolved oxygen produces rapid corrosion of the

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* *Proceedings of the Royal Academy of Sciences*, Amsterdam, 1913, vol. xvi. p. 485.
† *Comptes Rendus*, 1914, vol. clviii. p. 404.   ‡ *Metal Industry*, 1914, vol. vi. p 22.

copper, whilst the effect of carbon dioxide on the rate of corrosion is scarcely appreciable in salt water.—D. E.

Crystal Growth in Metals.—Resulting from experimental work with a specially designed long-focus microscope,* the growth of the poly- hedral structure of metals and alloys on heating is described by F. Robin.†

The grain-structures of metals are classified as primary (grains of soli- dification), characterized by highly curved boundaries; and secondary grains (obtained on annealing after plastic deformation), which usually have more or less rectilinear boundaries.

Examinations of primary grain-structures were made by noting the networks formed on the free surfaces of pure lead, tin, and aluminium when solidifying under the microscope. By subsequent etching these network patterns were found truly to express the arrangement of the underlying grains of the metal.

An analogy is drawn between the networks produced on the free sur- faces of a metal on solidification and the contraction patterns obtained by the drying up of a layer of muddy water, or by the dessication of a viscous fluid such as glue; and a very tentative suggestion is made that when a pure metal solidifies it is at first amorphous, changing almost immediately to the crystalline condition. In support of this unusual view, the author states that impurities in the metal or mechanical disturbances during freezing (both of which tend to produce a progressive solidification, as distinct from the sudden solidification of a pure metal) were found effectually to prevent the formation of the surface network. It is suggested that the surfusion commonly associated with the solidification of pure metals may be due to the crystallization of the already solid metal.

Immediately following the complete solidification of metals in the above experiments, a feathery pattern was found to appear on the free surfaces of the cast metals. This pattern increases in clearness as the temperature of the now solid metal falls. This is attributed by the author to unequal contraction strains in the cooling mass.

Secondary grain-structures obtained on annealing cold-worked metal are also described. Such structures are usually more regular than those found in cast metals. On heating a polished sample of cold-worked metal the boundaries of the underlying grains appear upon the polished surface at a certain definite temperature, which is stated to vary from 60° C. for tin to 500° C. for nickel. The author attributes this pheno- menon to unequal expansion of the crystal grains in different directions; but such an explanation is questionable, since most metals crystallize in the cubic system of symmetry, wherein expansion is equal in all directions.

With continued rise of temperature the surface pattern is modified in accordance with the growth of the crystal grains until the melting-point of the metal is almost attained, when the grains disintegrate from each other. An interesting comparison is made between the polygonal cell-

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* See *Journal of the Institute of Metals*, 1913, No. 1, vol. ix. p. 228.
† *Journal de Physique*, 1914, vol. iv. p. 37.

structure of a mass of metal, and the cell-structure observed by compressing a froth of soap bubbles in a glass vessel.

The growth of crystal grains on annealing may be predatory, a given grain growing at the expense of its neighbours; but it was also found in some cases that growth occurred by the union of neighbouring grains in a wholesale manner. Where new grains are formed their first appearance is to be looked for at the intersection of several of the previously-existing grain boundaries.

It is concluded that the grain-structure of strained and annealed metal shows a greater tendency towards the production of large crystal grains than does the grain-structure of cast metal. The presence of impurities generally exercises a restraining influence on the size of the annealed grain-structure and on the rate of growth.

No details are given in the paper of the experimental methods by which the results described therein have been attained. Such details are presumably to be found in the author's earlier work, since appropriate references are appended.—D. E.

Crystalline and Amorphous Metals.—A summary of work on this subject is given by W. Rosenhain.* The work of Beilby is reviewed and defended against the criticisms of Heyn and Tammann. Polishing, however, is regarded as partly chemical, and not as purely physical. Good polish on metals can only be obtained by the use of metallic oxides, which may be assumed to penetrate into the amorphous layer. Thus, the chemical properties of a glass surface depend on the nature of the oxide used in polishing, and silver, polished with " soft " rouge, after a time shows dark specks of ferric oxide, which have been taken into the surface layer and then rejected, probably on account of partial recrystallization.

Benedicks has suggested that twin-lamellæ are formed along the gliding planes in strained metals, but the evidence goes to show that twin-lamellæ do not arise until after annealing. Beilby's view, that an amorphous layer is formed, is more probable. Tammann's objection, that pressure would not encourage the formation of the amorphous phase because this is less dense, is not conclusive, because it is not certain that the effect of mechanical strain is to increase the " hydrostatic " pressure. Johnson and Adams have gone so far as to indicate how the liquid phase could be produced at low temperatures by unequal pressure.

The existence of spongy platinum and palladium is a proof that amorphous metals may exist at temperatures far below their melting-point.

Intercrystalline boundaries are surfaces of strength, not of weakness, as is strangely assumed by Tammann. The behaviour of metals under alternating stress is best explained by the assumption of an amorphous intercrystalline cement, which behaves as an elastic skin. This also explains the temporary plasticity and recovery of strained metal. It still remains to be shown why only certain pure metals and solid solutions are plastic at the ordinary temperature, and why intermetallic

* *International Journal of Metallography*, 1913, vol. v. pp. 65–106.

compounds are almost invariably very brittle. The hypothesis of an intercrystalline amorphous cement in unstrained metals is then explained and illustrated from the author's papers. Surface tension is considered insufficient to explain such phenomena as those of the growth of grains in crystal aggregates, where free surfaces do not exist. The formation of long dendrites, projecting into the liquid during crystallization, and offering almost a maximum of surface, is also opposed to the view that surface tension has any very important influence. It appears that small quantities of impurity may increase the mobility of the amorphous layer.

Rosenhain's views are critically discussed by W. Guertler,[*] who considers that the great stability of the crystalline state in metals, and the readiness with which it is formed, are opposed to the existence of masses of amorphous material. Spongy platinum, &c., is metastable, but probably not amorphous. Further, the properties attributed to the hard amorphous phase are in some respects contradictory.

The presence of an intercrystalline cement is accepted, and is illustrated by diagrams. This cement is not truly amorphous, but crystalline with a distorted space-lattice. The term "meta-crystalline" or "para-crystalline" is preferable to "amorphous." The layer must, however, be of molecular dimensions. Any thicker layer must be considered as made up of irregular detritus.

Rosenhain's views are also criticized by R. von Moellendorff,[†] who objects to the term "amorphous," and regards the strained metal as containing crystals, the space-lattices of which are distorted.—C. H. D.

Density of Liquid Metals.—Further determinations of this property have been made by P. Pascal and J. Jouniaux,[‡] by weighing a quartz sphere immersed in the molten metal. The following values, considered to be accurate to 0·01, have been obtained :

	At Melting-point.	400° C.	600° C.	800° C.	1000° C.	1200° C.
Tin . . .	6·98	6·86	6·77	6·69	6·56	...
Lead . . .	10·875	10·85	10·71	10·49	10·15	...
Zinc . . .	6·92	...	6·81	6·57	...	...
Antimony . .	6·55	...	...	6·48	6·36	...
Aluminium . .	2·41	...	...	2·36	2·29	...
Copper . .	8·40	...	...	...	...	8·32

An atmosphere of inert gas was used. The tin curve has a point of inflexion at 620° C.—C. H. D.

Emission of Electrons.—The emission of electrons from a heated tungsten filament has been further investigated by O. W. Richardson.[§]

[*] *International Journal of Metallography*, 1914, vol. v. p. 213.
[†] *Ibid.*, vol. vi. p. 44.
[‡] *Comptes Rendus*, 1914, vol. clviii. p. 414.
[§] *Philosophical Magazine*, 1913, ser. vi., vol. xxvi. p. 345.

When the filament is heated in a high vacuum, the number of electrons emitted is compared with the number of gas molecules evolved, as determined from the rise in pressure, and is found to be many million times greater. Liquid air and charcoal do not affect the emission. The mass of the electrons thus emitted amounts to as much as 4 per cent. of the weight of the tungsten, and is greater than the loss of weight of the filament (determined, however, by the change of resistance, and not by weighing). The experiments are regarded as proving that the current in metals is conveyed by electrons, the excess of electrons emitted thus having flowed in from the outer circuit.—C. H. D.

Erosion of Bronze Propellers.—An article by Mr. William Ramsay * on the deterioration of high-speed propellers has been the subject of discussion in *Engineering*.

Sir W. Ramsay † expresses his opinion that the injurious effects often noted in bronze propellers are due to erosion rather than corrosion of the metal. In support of this contention, it is pointed out that there appears to be a certain critical speed, below which no deterioration takes place, whilst above this speed loss of metal is rapid.

The best high-speed propellers are now usually made of an alloy which, judging by its composition, should be harder than the old bronze alloy and yet more liable to corrosive influences; this, again, would suggest that the loss of metal is to be attributed to an erosive or scouring action rather than to simple corrosion.

The possibility of scouring and corrosive effects conjointly causing deterioration is not discussed.

Replying to Sir W. Ramsay's communication, Mr. Ramsay ‡ expresses his opinion that, as the result of practical experience, there is no critical speed, as asserted, below which deterioration of bronze propellers does not take place. The dissolution of the metal he ascribes mainly to corrosive influences, against which protective plates of zinc are of little avail.

A further communication from E. W. Sergeant § relating to the failure of bronze impellers of high-speed centrifugal pumps, describes the reduction of the metal to a spongy condition, and on this account he attributes deterioration to corrosive rather than to erosive agencies. The dissolution of impellers pumping acid or alkaline water is stated to be quite different in nature from the sponginess described above, which has been noted in both steam and electrically-driven pumps.—D. E.

Feebly Magnetic Alloys.—The susceptibility of some feebly magnetic alloys has been determined by Faraday's method by E. L. Dupuy.‖ The alloys of silver and antimony give a curve with a sharp cusp corresponding with the limits of the solid solutions formed by the compound Ag_3Sb. Alloys of lead and tin give a straight line, with a branch at the lead end corresponding with the solid solution, and a very short branch of the same kind at the tin end. Alloys of aluminium and zinc

* *Engineering*, 1912, vol. xciii. p. 687.   † *Ibid.*, 1913, vol. xcvi. p. 690.
‡ *Ibid.*, 1913, vol. xcvi. p. 761.   § *Ibid.*, 1913, vol. xcvi. p. 726.
‖ *Comptes Rendus*, 1914, vol. clviii. p. 793.

show a break at the composition Al$_3$Zn, which, it is suggested, exists in a largely dissociated condition.—C. H. D.

Grey Tin.—According to A. Wigand,* grey tin has always a smaller specific heat than white tin, the values between 0° and +15° being: grey 0·0510, white 0·0525. As the densities are 5·85 and 7·30 respectively, tin forms an exception to Richarz's rule, according to which the denser modification has the lower specific heat. On the other hand, it accords with the general rule that the modification stable at the higher temperature has the higher specific heat. The molecular change at the transformation point, like that of ice or bismuth at the melting-point, must be of an exceptional character.—C. H. D.

Hardness.—Brinell hardness tests made by J. H. Andrew † with the alloys of copper with aluminium and tin show that, contrary to the assumption generally made, an alloy which is a solid solution at high temperatures, breaking up into its components on cooling, is not always hardened by quenching. Thus, whilst copper alloys containing 10 to 11 per cent. of aluminium are hardened by quenching, those with 12 to 13 per cent. are much softer in the quenched than in the slowly-cooled state. Copper alloyed with 20 to 28 per cent. of tin is also softened by quenching.

A very full summary of the facts relating to hardness and plasticity is given by N. S. Kurnakoff and S. F. Schemtschuschny,‡ with special reference to the method of determining the pressure required to produce plastic flow. It is shown that the Brinell hardness is, like the pressure required to produce flow, a measure of the internal friction. In some cases, such as that of lead, the hardness is found to be a more sensitive means of detecting minute quantities of impurities than the electrical conductivity. Highly purified metals are much softer than the commercial varieties.

The modulus of elasticity of a solid solution is equal to or smaller than the arithmetical mean of the values for its components, whilst for definite compounds it is always greater.—C. H. D.

Hardness and Conductivity of Alloys of Cadmium and Zinc.—These alloys have been examined in the cast state by A. Glasunoff and M. Matweeff.§ The conductivity is directly proportional to the atomic concentration. The hardness, determined by Brinell's method, shows a maximum at the eutectic composition, even when the alloys have been annealed at 225° C. for seventy-two hours. After hammering and annealing at 225° C. for 900 hours the maximum disappears, and the hardness becomes a straight line. The change must be a purely physical one, and is probably accounted for by the fine grain of the original metal, cast in glass tubes.—C. H. D.

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* *Zeitschrift für Elektrochemie*, 1914, vol. xx. p. 38.
† *International Journal of Metallography*, 1914, vol. vi. p. 30.
‡ *Jahrbuch der Radioaktivität und Elektronik*, 1914, vol. xi. p. 1.
§ *International Journal of Metallography*, 1913, vol. v. p. 113.

Melting-point of Arsenic.—This has been determined by R. Gobau [*] to be 817°, using a thick-walled quartz vessel. On the other hand, P. Jolibois [†] has obtained, by a similar method, the values 852° and 849°. The metal may be undercooled as much as 50°. The vapour is yellow.—C. H. D.

Minimum Annealing Temperature.—Measurements by Hanriot and Lahure [‡] show that the softening of cold-rolled silver, as determined by the ball test, is quite perceptible after four hours at 100°. The hardest metal begins to soften at the lowest temperature, and when the softening has once begun, it proceeds so rapidly that, for the same temperature, it becomes softer than the metal which was originally less hardened. Zinc and aluminium behave similarly. Time, as well as temperature of annealing, must always be taken into account.—C. H. D.

Molecular Changes in Metals and the Quantum Hypothesis.—Under this title C. Benedicks [§] discusses the importance of Planck's hypothesis of quanta for metallography. The hypothesis has been generally adopted, because it is impossible to explain the law of the partition of energy on the ordinary assumptions. It appears, however, simpler to abandon the usual view of the monatomic character of solids, and to assume instead an agglomeration of atoms, increasing with falling temperature, according to Langevin's law for magnetic substances. On this assumption it is possible to arrive at Planck's law of partition of energy without the assumption of energy quanta, the process of agglomeration providing the discontinuity which is now known to be inevitable.—C. H. D.

Optical Orientation of Metallic Crystals.—Using Koenigsberger's method of examining the polarization of the reflected light, K. Endell and H. Hanemann [||] have determined the optical orientation of the crystals in several cast metals. This method is applicable to any isotropic metal. Zinc and antimony, cooling freely in a crucible, form uniformly orientated crystals, the optical axes of which are perpendicular to the cooling surface. Agitation destroys the uniformity, and it has not been found possible to obtain quite uniform orientation in either bismuth or tin.

Antimony crystallites, separating from an alloy with lead, also crystallize perpendicularly to the cooling surface, probably also from its alloys with silver. Crystallites of bismuth in its alloy with cadmium, and of tin in its alloy with silver, are apparently irregular in their orientation. These experiments are being continued with a specially designed apparatus.—C. H. D.

Palladium and Hydrogen.—The occlusion of hydrogen by palladium has been further studied by F. Halla,[¶] whose results are brought into comparison with those of Holt and his fellow-workers. Palladium black prepared by Graham's method is always somewhat active.

* *Comptes Rendus*, 1914, vol. clviii. p. 121.   † *Ibid.*, p. 184.   ‡ *Ibid.*, p. 263.
§ *International Journal of Metallography*, 1913, vol. v. p. 107.
|| *Zeitschrift für anorganische Chemie*, 1913, vol. lxxxiii. p. 267.
¶ *Zeitschrift für physikalische Chemie*, 1914, vol. lxxxvi. p. 496.

No influence can be observed when active and inactive palladium are brought into contact.—C. H. D.

Passage of X-rays through Metals.—Some experiments by H. B. Keene,* on the passage of X-rays through metals, are mentioned. A pencil of X-rays was made to impinge normally upon sheet metal, a photographic plate being placed behind the metal sheet, and about 1 inch distant from it. The nature of the patterns obtained differs considerably for rolled and annealed metal.—D. E.

Passivity of Metals.—Further investigations into the meaning of passivity have been conducted by W. Rathert,† the conclusions being in favour of the hydrogen theory. The potential at which a metal becomes passive is not a true transition point, and is not the same as that at which it becomes active in the opposite direction, as the oxide theory would require. The passage from the one state to the other is sharp in the case of iron and chromium, but gradual in that of nickel. Chromium, rubbed with emery in an atmosphere of hydrogen, is not active, but passive. Passive chromium becomes active when charged electrolytically with hydrogen. Molecular hydrogen is practically without influence on the potential of passive chromium.—C. H. D.

Photo-electric Effect.—The selective photo-electric action of metals has been further examined by G. Reboul.‡ The action is determined, first using light from a mercury lamp passing only through a quartz plate, and then, with the same light passing through a similar plate thinly silvered, to filter out all but the ultra-violet light. The emission in the latter case is always smaller (R.). The values n represent the values for the frequency of the resonator, calculated by Lindemann's formula :

$$n = k \sqrt{\frac{D}{A}}$$

where D is the density and A the atomic weight :

Metal.	R.	n (arbitrary units).
Silver	176	0·3119
Gold	174	0·3125
Platinum	150	0·3312
Copper	153	0·3730
Iron	129	0·3748
Nickel	121	0·3845
Tin	119	0·2491
Lead	99	0·2388
Aluminium	22	0·3085
Zinc	30	0·3301

—C. H. D.

* *Engineering*, 1913, vol. xcvi. p. 447.
† *Zeitschrift für physikalische Chemie*, 1914, vol. lxxxvi. p. 567.
‡ *Comptes Rendus*, 1914, vol. clviii. p. 477.

Polymorphic Changes of Thallium, Tin, Zinc, and Nickel.— Detailed investigations by M. Werner * show that thallium has a transformation temperature of 226° C., which is lowered by pressure, becoming 220° C. under 3000 kg./cm.². The change of volume at the transformation point is 0·000044 cc./g., from which the heat of transformation is calculated to be 0·26 ± 0·07 calories per gramme, whilst the value obtained by Tammann's method from the cooling curve is 0·24. The electrical resistance changes discontinuously at the transformation point, and hard wire gives a different value from soft. There is a similar discontinuity in the thermo-electric force measured against copper.

Tin shows a discontinuity of electrical properties at 160° C. The heat of transformation : tetragonal → rhombic tin is 0·02 calories per gramme, and the increase of volume 0·00017 cc./g.

The transformation of zinc occurs at 304° C., and a change at 170° C. has not been confirmed.

The transformation of nickel occurs at 352° C., the heat change being 0·013 calories per gramme. This corresponds with the magnetic change. Hard and soft nickel behave alike, and the change is not accompanied by any alteration of volume.—C. H. D.

Resilience of Copper Alloys.—The resistance of copper alloys to shock at varying temperatures has been determined by L. Guillet and V. Bernard,† using seven bronzes containing from 3·5 to 20 per cent. of tin, and varying quantities of lead and zinc, four brasses, and one aluminium-copper alloy. In all cases the resilience diminishes with increasing temperature, falling sharply in the region 200° to 300° C. In some few cases there is a decided recovery at about 700° C. Lead greatly increases the fragility both of brasses and bronzes.—C. H. D.

Resistivity of Gold from 20° to 1500°.—The electrical resistance of gold has been determined by E. F. Northrup,‡ using an apparatus similar to that employed for copper, but of smaller size. The best proportions for the material of the container · are : magnesite, 45 ; alundum, 55 parts. The increase of resistivity with temperature of liquid gold is linear, and with solid gold nearly so, and the ratio of the resistivities at the melting-point is 1 : 2·28.—C. H. D.

Specific Heat of Alloys.—Certain anomalies have been observed by O. Richter.§ The rule that an element which can exist in several polymorphic modifications has the greatest specific heat in that state in which it has the smaller density, has been confirmed without exception. As the density of alloys frequently does not follow the mixture rule, their specific heats have been investigated from this point of view. The alloys of bismuth and tin have densities and specific heats which deviate

* *Zeitschrift für anorganische Chemie*, 1913, vol. lxxxiii. p. 275.
† *Comptes Rendus*, 1913, vol. clvii. p. 548.
‡ *Journal of the Franklin Institute*, 1914, vol. clxxvii. p. 287.
§ *Annalen der Physik*, 1913 [iv.], vol. xlii. p. 779.

only slightly from the mixture rule (density being plotted against composition by volume), and the deviations are such that the higher specific heat corresponds with the lower density. With alloys of lead and bismuth the density only deviates slightly, but the specific heat deviates very widely, and in the same direction as the density, contrary to the above rule. It is found that the temperature of casting influences the specific heat of these alloys, this being smaller when the cooling is slower. This is provisionally attributed to the formation, during slow cooling, of larger molecular aggregates. The presence of a maximum in the specific heat curve of the alloys of bismuth and lead is attributed to a possible compound. (There is some confusion in the paper between compounds and eutectics.)

A further study of such anomalies has been made by E. Dippel,* who finds that the variation of specific heat with the rate of cooling is connected with a variation of the melting-point. The melting-point of alloys of lead and bismuth is found to depend on whether the alloy is overheated before cooling, or is merely raised to a temperature of a few degrees above the melting-point. [The form of the cooling curves is such as to indicate a very considerable lag of the thermocouple, the freezing-point being very indistinctly marked. Also, no analyses have been made, so that the presence of oxide in the overheated alloys is quite possible.]

These phenomena are compared with the phenomenon of ageing in the Heusler magnetic alloys, and are considered to afford a proof of the formation of molecular complexes.—C. H. D.

Specific Heat of Sodium.—The specific heat of liquid and solid sodium has been determined very accurately by Ezer Griffiths,† using 366 grammes of pure metal enclosed in a thin copper sheath. The specific heat increases in the solid state with the temperature, and in the liquid state falls more slowly with increasing temperature. The specific heat in the solid state varies with the previous heat treatment. Slowly cooled metal is in an " annealed " state, whilst rapidly cooled, or " quenched " metal gives different values. Up to 75° the quenched metal has the higher specific heat, above that the annealed metal gives the higher values. Both series of determinations are exactly reproducible.

The latent heat of fusion is 27·1 calories per gramme.—C. H. D.

Surface Films produced in Polishing.—Further evidence for the amorphous character of the film produced in polishing metals is afforded by the experiments of G. T. Beilby.‡ When copper is polished the minute cavities due to inclusion of gas are sometimes covered over by the surface film, and are then found to be transparent or translucent, so that the floor of the cavity may be seen through them. The thin film has a blue tinge. The paper is illustrated by high-power photographs in colour.—C. H. D.

* *Annalen der Physik*, 1913 [iv.], vol. xlii. p. 889.
† *Proceedings of the Royal Society*, 1914, vol. lxxxix. *A*, p. 561.   ‡ *Ibid.*, p. 593.

Viscosity and Density of Fused Metals.—Interesting experiments have been made by R. Arpi,* using a silica viscosimeter. The metals are fused in a reducing atmosphere in a graphite crucible, and then drawn into the viscosimeter by means of a vacuum pump. The whole apparatus is so arranged that a very constant temperature is maintained throughout its length by electrical heating, a thick copper tube with windows immediately surrounding the silica tube. The atmosphere used is hydrogen, except when cadmium and bismuth are used, when it is necessary to use a mixture of hydrogen and methyl alchohol vapour.

Comparing together the metals tin, cadmium, mercury, lead, and bismuth, it is found that the viscosities are all of the same order; so that at 350° C., for instance, the highest value for lead is only twice the lowest value, that of mercury. The greater the viscosity (for all these metals except bismuth) the more rapidly does it decrease with falling temperature. The viscosity of bismuth falls less rapidly with the temperature than that of the remaining metals. At a given temperature the viscosities are in the same order as the melting-points. Cadmium and lead have nearly the same melting-point, and lead, with the higher atomic weight, has the greater viscosity, this being in accordance with the general rule for organic substances.

The viscosity of the alloys of lead and tin is almost exactly an additive property, the small deviations being in the direction of a smaller viscosity than that calculated from the mixture rule. With alloys of lead and bismuth the viscosity is decidedly less than that calculated, and the temperature-coefficient is also less than that of the pure metals.

By using a silica vessel as a pyknometer, the densities have also been determined at different temperatures. The density of the liquid alloy is always somewhat less than that calculated by the mixture rule.

The composition of the alloys is expressed in percentages by volume. —C. H. D.

Volume changes in Amalgams.—Measurements by J. Würschmidt,† show that tin amalgams expand considerably on melting. Zinc amalgams behave somewhat differently. The maximum expansion occurs, not at the melting-point, but considerably below it, and depends on the previous thermal history of the amalgam. This is due to a transformation which occurs slowly in the solid state, accompanied by change of volume.

Bismuth amalgam, like pure bismuth, contracts on melting, but the contraction begins considerably below the melting-point. There are two maxima, one below and one at the melting-point. Bismuth itself does not exhibit this behaviour.—C. H. D.

* *International Journal of Metallography*, 1914, vol. v. p. 142.
† *Berichte der deutschen physikalischen Gesellschaft*, 1913, vol. xv. p. 1027.

ELECTRO-METALLURGY.

Adhesion of Electrolytically-deposited Metals.—Experiments on this subject have been made by M. Schlötter.* A small copper block is soldered with soft solder to the plated surface, and the force is determined, which suffices to tear the deposited metal from the basis.

The hardness of the basis metal is of importance. Thus nickel adheres much more firmly to lead than to steel. The influence of other factors is also discussed generally.—C. H. D.

Duplicating Phonograph Discs.—A process described by P. M. Grempe † consists in polishing copper during the process of deposition by means of an agate burnisher, as in the Elmore process of making tubes. High current densities may thus be used, and matrices up to 2 millimetres thick are readily prepared. From these copies are made in the usual way.—C. H. D.

Electrolytic Copper Refining.—Some experiments have been made by C. W. Bennett and C. O. Brown, ‡ to determine the best method of working with high current densities. For the laboratory an aluminium tube $1\frac{1}{16}$ inch outside diameter is rotated about a vertical axis, being geared to a half horse-power motor, so that speeds up to 5500 revolutions per minute may be obtained. With 70 amperes per square decimetre, 125 grammes of copper may be deposited in an hour and a half. This is enough to test the refining process. With cast anodes containing 1 per cent. of silver, silver is found in the deposit unless cloth diaphragms are used. With an anode containing 91 per cent. of copper and about 1 per cent. each of silver, lead, iron, nickel, bismuth, arsenic, zinc, and carbon, the deposit is up to the standard of average electrolytic copper. The cathode deposit is readily stripped off the aluminium.—C. H. D.

Electro-metallurgy of Zinc.—In a general discussion of present-day metallurgical problems, D. A. Lyon § refers to the electric smelting of zinc ores. The subject is discussed under two heads :—

(1) The zinc is extracted by the reduction of the ore (calcined, if necessary) with carbon and carbon monoxide.

The reactions taking place in the electric furnace are in this case identical with those which take place when the old retort smelting

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* *Chemiker-Zeitung*, 1914, vol. xxxviii. p. 289.
† *Elektrochemische Zeitschrift*, 1914, vol. xx. p. 353.
‡ *Journal of Physical Chemistry*, 1913, vol. xvii. p. 685.
§ *Journal of the Franklin Institute*, 1914, vol. clxxvii. p. 216.

furnace is employed, but the electric furnace possesses the advantages of being continuous working and having a greater thermal efficiency.

It is stated that in the electric furnace process the reduction seems to take place more rapidly than in retort smelting, but the reaction

$$CO_2 + C = 2CO$$
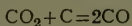
does not seem to occur to such an extent in the electric furnace as in the retort. Hence the electric furnace contains an atmosphere comparatively richer in carbon dioxide, so that a larger amount of "blue powder" (slightly oxidized zinc deposit) is formed than when the retort furnace is employed.

(2) Extraction is effected by employing iron to sulphurize the blende of the ore.

Here again the deposited zinc powder is often found to be oxidized.

The metallurgical problem requiring solution in connection with this particular subject is stated as the discovery of some means of avoiding oxidation of the zinc deposits as formed under the conditions prevailing in electric smelting practice.—D. E.

Growth of Electro-chemical Industries.—A general review of this subject is given by H. Gall,* in a presidential address to the Society of Civil Engineers of France.—C. H. D.

* *Journal du Four Electrique*, 1914, vol. xxiii. pp. 601, 631.

ANALYSIS AND TESTING.

CONTENTS.

I.—*ANALYSIS.*

Aluminium Analysis.—A course of operations for the analysis of the commercial metal is described by H. P. Bhattacharyya.* Iron and copper are estimated gravimetrically. For the aluminium, the solution, after removal of silica and copper, is mixed with sodium phosphate. Ammonia is then added until a precipitate appears, and this is just redissolved with hydrochloric acid. It is then boiled, and an excess of sodium thiosulphate is added. After boiling off all sulphur dioxide, the precipitate is collected and weighed as $AlPO_4$. The filtrate is made ammoniacal and boiled until neutral. This precipitates zinc phosphate. Sodium is estimated as chloride, and carbon by wet combustion after treatment with sodium copper chloride.—C. H. D.

Atomic and Weight Percentages.—It is pointed out by E. Jänecke † that he has previously described the graphical method of converting atomic percentages into percentages by weight and *vice versa*, lately published by von Pirani. The construction may be applied also to ternary systems.

In a short note, M. von Pirani ‡ admits Jänecke's priority.—C. H. D.

Calibration Tables for Thermocouples.—Calibration tables are given by L. H. Adams § for copper-constantan and platinum-platinum-rhodium couples. The temperature and temperature-difference are given for every 100 microvolts. An actual couple may be used with these tables after calibration at three or more temperatures and construction of a deviation curve.—C. H. D.

Colorimetric Estimation of Nickel.—Potassium thiocarbonate is recommended by V. Lindt * as a reagent for nickel. In alloys, copper and lead should be first removed by hydrogen sulphide, and iron by ammonia. The solution may still contain zinc. The solution is made ammoniacal, and made up to 20 cubic centimetres. Then 0·5 cubic centimetre of a 4 per cent. solution of potassium thiocarbonate is added, and the colour is compared with a standard. The best concentration of the nickel is from 0·102 to 0·017 milligramme per cubic centimetre. The method is rapid and cheap.—C. H. D.

Commercial Nickel.—L. Bertiaux † recommends dissolving in a mixture of hydrochloric and sulphuric acids, adding an excess of ammonia, and depositing nickel, cobalt, and copper together electrolytically. The deposit is then dissolved in nitric acid, the copper estimated electrolytically, the cobalt as cobaltinitrite, and the nickel electrolytically. Iron, manganese, aluminium, calcium, and magnesium may be estimated in the liquid from the first deposit. Silica and sulphur are estimated in a separate sample, arsenic and antimony by distillation, and carbon by combustion.—C. H. D.

Deposition of Lead on the Cathode.—It is shown by R. Garten-meister,‡ that the deposition of lead on the anode may be avoided and quantitative cathodic deposition obtained by adding gallic acid. With lead up to 1 gramme, 2 to 2·5 cubic centimetres of concentrated nitric acid are used, with 5 grammes of gallic acid, 5 to 6 cubic centimetres of alcohol, diluted to 125 cubic centimetres. A platinum foil anode and platinum gauze cathode are used, without rotation. With a current of 1·2 amperes, four hours at 65° to 70° C. are required. Copper is deposited with lead, and arsenic, tin, and antimony make the deposits rough, but most other metals do not interfere.

Alloys of lead, tin, and antimony may be analysed by separating the lead with sodium sulphide, washing first with sodium sulphide, and then with ammoniacal ammonium chloride, and sulphide, dissolving in nitric acid, evaporating to dryness, again dissolving in nitric acid, and electro-lyzing as above.—C. H. D.

Electrolytic Analysis of White Metals, with Tin Basis.—A rapid and accurate method is described by I. Compagno.§ One gramme of the alloy is covered with 20 cubic centimetres of nitric acid (D. 1·4), and after standing several hours is heated for thirty minutes on the water-bath. The tin and antimony oxides thus obtained contain only a little copper. Copper and the small quantities of lead are estimated electrolytically in the filtrate. The precipitate is dissolved in sodium hydroxide and sodium sulphide and electrolyzed. Any copper deposited

* *Zeitschrift für analytische Chemie*, 1914, vol. liii. p. 165.
† *Annales de Chimie analytique*, 1913, vol. xviii. p. 377.
‡ *Chemiker-Zeitung*, 1913, vol. xxxvii. p. 1281.
§ *Atti Reale Accademia dei Lincei*, 1913 (v.), vol. xxii. (ii.), p. 221.

with the antimony is estimated by a special method, depending on the precipitation of cuprous oxide.

The liquid from the antimony deposit is heated, and treated cautiously with 120 cubic centimetres of hydrochloric acid. Boiling is continued until the precipitate of tin sulphide is redissolved, and after concentration a little hydrogen peroxide is added, followed by 20 grammes of oxalic acid. The tin is then deposited from the warm solution on a rotating cathode.—C. H. D.

Fine-meshed Brass Gauze as a Substitute for Platinum in Electro-analysis.—Some results in the electrolytic determination of copper, nickel, and zinc, in which fine-meshed brass gauze, copper coated, is used as cathode in place of platinum, are given by D. F. Calhane and T. C. Wheaton.*

Brass gauze 100 mesh to the inch was chosen because it is obtainable in finer mesh than copper and it is also tougher. In making the cathode the gauze is cut into pieces $5\frac{1}{4}$ inches long and $3\frac{1}{4}$ inches wide. The longer edges are lapped over and hammered down. The shorter edges are bent over a 12-inch loop of No. 22 copper wire and the ends of the wire twisted together, thus forming a cylinder weighing about 12 grammes. For use with ammoniacal solutions, that portion of the copper wire stem in the neighbourhood of the surface of the electrolyte which would be attacked by ammoniacal fumes, must be replaced by platinum. Two pieces of platinum wire 3 inches long are attached to the gauze and twisted together, their other ends being joined to the copper wire stem. A thin coating of copper is plated on the gauze before use. Using the cathode described above, it was found that with strong currents and no rotation the heat and gas evolution stirred the solution very adequately, and that the time factor for the brass gauze with still electrolyte was very nearly as good as for platinum gauze with magnetic stirring. In the determination of copper in German silver in the presence of sulphuric and nitric acids, using a platinum wire spiral as anode, it was found possible to deposit completely between 0·3 and 0·4 gramme copper in 45 to 50 minutes, using a current of 5 amperes for seven minutes and 1 ampere for forty minutes.

Bright, firmly adherent deposits of nickel were obtained from ammoniacal solutions using current up to 4 amperes. Thirty determinations of zinc were carried out from sodium zincate solutions prepared as follows: The sample was dissolved in dilute nitric acid and the solution evaporated to dryness. The dish was then heated over an iron plate with 4 cubic centimetres sulphuric acid (s.g. 1·84), leaving the zinc finally as sulphate. The residue was moistened with a little sulphuric acid and taken up in 25 cubic centimetres of water. A 3 per cent. excess of caustic soda, over and above that required for the conversion of all the zinc present into sodium zincate, was then added in the form of a solution two to three times normal strength. The gauze cathode and spiral anode were placed in a dry beaker, and all connections made for the flow of

current. The hot solution of sodium zincate was then poured into the beaker, the current starting to flow immediately.

A temperature of 60° C., with a current of 4 amperes for the first five minutes and 1 ampere for the rest of the time, was employed. Under the above conditions 0·3 gramme zinc was deposited in about forty minutes. The deposits were light-coloured, non-crystalline, and firmly adherent. The following results are given, using zinc sulphate :—

Weight of $ZnSo_4.7H_2O.$	Weight of Zinc Deposited.	Percentage of Zinc Found.	Remarks.
Grammes.	Grammes.		
1·1626	0·2768	23·817	No stirring.
1·0449	0·2488	23·81	Magnetic stirring.
1·0394	0·2476	23·82	,, ,,
1·1429	0·2720	23·80	,, ,,
1·1429	0·2720	23·80	No stirring.

—S. L. A.

German Silver Analysis.—The process recommended by C. Lind * consists in estimating the copper electrolytically in nitric acid solution, neutralizing the liquid with ammonia, acidifying with two drops of dilute nitric acid, and saturating with hydrogen sulphide. The zinc sulphide is washed with ammonium chloride, dissolved in dilute sulphuric acid and made strongly alkaline with potassium hydroxide. The zinc is then deposited electrolytically on a gauze electrode freshly coated with copper. With 4 volts and 0·8 to 1 ampere, 0·1 gramme of zinc is deposited in an hour. Nickel is estimated in the solution by precipitation with dimethylglyoxime.—C. H. D.

Micro-chemical Recognition of Aluminium.—Material suspected to contain aluminium, according to F. Rathgen,† is heated in a platinum crucible with solid ammonium fluoride and a few drops of concentrated sulphuric acid. After evaporating to dryness, the crucible is momentarily heated to redness. After detaching the solid and examining under the microscope, aluminium is recognized by the small hexagons, colourless or faintly coloured, of alumina.—C. H. D.

Palladium Estimation.—Palladium may be estimated in presence of small quantities of copper and iron, according to M. Wunder and V. Thüringen,‡ by adding a hot solution of α-nitroso-β-naphthol to the boiling solution containing much hydrochloric and acetic acid. The precipitate is collected, washed with hot 5 per cent. hydrochloric acid and then with hot water, ignited, first in air and then in hydrogen, and cooled in carbon dioxide.—C. H. D.

* *Chemiker-Zeitung*, 1913, vol. xxxvii. p. 1372.
† *Zeitschrift für analytische Chemie*, 1913, vol. liii. p. 33.
‡ *Ibid.*, vol. liii. p. 737.

II.—*TESTING.*

Hardness Testing.—The construction and method of use of the Martens Hardness Tester, accompanied by diagrams and results obtained with various metals, are described by an anonymous correspondent.*

Hardness may be defined as the resistance to any permanent deformation. Its relative magnitude is of great importance. Among recent suggestions for determining hardness that of Martens has the great advantage of simplicity.

Like Brinell, Martens uses a hard steel ball, but measures depth of impression instead of diameter, as a basis for the necessary calculations. The specimen is forced by a measured hydraulic pressure, vertically up against the steel ball, which is held magnetically in a socket fixed in a cross-member immediately over the test-piece. Three pins or feelers, capable of free up-and-down movement, are symmetrically arranged round the ball in this socket. During the test the lower ends of these feelers are in contact with the surface of the specimen and the upper ends with a freely moving piston. Over this piston is a well of mercury communicating with a capillary attached to a graduated and calibrated scale. The depth to which the ball is forced into the specimen is measured by means of the upward movement of the three feelers, which is communicated through the piston to the mercury, causing it to rise in the capillary. The height above zero of the mercury in the capillary is a measure of the depth of the impression.

The scale is divided into $\frac{1}{500}$th of a millimetre, each division being sufficiently large to allow of estimating to the nearest $\frac{1}{1000}$th of a millimetre depth of impression. The necessary pressure is produced by the ordinary town supply, and is recorded on a gauge divided into 300 degrees, each degree corresponding to 8·33 kilos, or a total pressure of 2500 kilos.

In making a test the pressure is gradually increased by definite amounts to the required maximum, and corresponding readings of pressure and mercury-level noted. The same procedure is gone through whilst the pressure is gradually released. A curve is then drawn connecting depth of indentation and load. The curves show the same characteristic feature, viz. a maximum and a permanent indentation for a certain maximum pressure. The partial recovery of the material indicated by the difference between the permanent and the maximum indentation is to be ascribed to the elasticity of the specimen, steel ball, and apparatus. In the necessary calculation the permanent indentation is the value which is of importance. In testing soft metals the mercury column will continue to rise, although the pressure remains constant. This fatigue effect can be made negligible by keeping the pressure indentations correspondingly low. Martens, in advocating a definite indentation base for comparing the hardness of materials, chose 0·05 millimetre as a convenient indentation, so as to eliminate this fatigue effect in ·the case of soft materials. In the course of experiment it was

* *Engineer*, 1914, vol. cxvii. pp. 281–283.

found that the relation of total pressure to depth of impression was not a direct one until a pressure P was reached, at which point

$$T = \cdot 032P + 3\cdot 5,$$

where   T = compressive stress in tons per square inch
and   P = the pressure in pounds as found in the curve.
This point is being further investigated.—S. L. A.

Testing of Metals.—In the first of two articles the present situation and modern tendencies in the testing of metals is reviewed by W. Rosenhain.*

In his opening address to the Sixth Congress of the International Testing Association at New York in 1913, H. M. Howe said that the art of testing would only reach its final development when it became possible to test the whole of the material to be used, not only before taking it into use, but in the finished structure, so that its condition could be watched over and the onset of any danger recognized in ample time.

The primary object of all testing is to secure that the materials used in construction shall be of "satisfactory" quality, but it is upon the manner of specifying what shall be regarded as satisfactory that the controversy always centres. The development of newer and more searching methods of examining materials, which is apparently so much dreaded by the less progressive manufacturer, is in reality the best friend of their industry, since it tends to open up for it newer and wider fields of application. General considerations lead to the very definite conclusion that in the testing of materials we should follow the method adopted with success in every form of experimental science, viz. the isolation of a series of separate factors, the others being temporarily eliminated, which means that we must determine as many of the simple physical constants of materials as possible, and then endeavour to correlate these and their various combinations with the behaviour of the materials in practice. The tensile test approaches fairly closely to the ideal advocated, "one test, one property," and it is for this reason that it yields concordant results almost entirely independent of type of testing machine and, when allowances are made for certain dimensional effects, of size or shape of specimen. Within wide limits even rate of testing scarcely affects results. In examining the numerous other forms of mechanical test which have been applied in recent years, the question to be asked in each case is: How nearly does this test approach to the ideal of determining a single well-defined property of the material? Properties ordinarily described as "strength," "toughness," "hardness," &c., are all more or less complex, and much further research is required to determine what really are true "fundamental" properties of our materials. The ordinary commercial tensile test neglects some of the most valuable data obtainable from this form of experiment. By the determination of the elastic limit and elastic modulus definite physical constants are measured, and correlation of these with service results

would certainly lead to the application of these tests for practical purposes. Thus a number of materials which had failed in service were found to give very satisfactory results so far as the ordinary commercial tensile properties were concerned, but in each case an exceptionally low elastic limit showed that the material was abnormal, which abnormality was finally traced to its source in the microstructure of the material and the treatment it had received.

Next to the tension test the property most utilized for testing purposes is that of hardness. Two types of hardness tests are in general use, viz. static impression either by means of a loaded ball (Brinell) or a loaded cone (Ludwik), and the striking of the surface of the specimen by a falling body whose height of rebound is measured. The rebound type of test must be classed as "complex," such factors as surface condition, elasticity, &c., besides "strength" or "hardness" enter into the results, which are not directly proportional to any one fundamental property of the metal. This form of test must therefore be considered as undesirable from the point of view of simplicity. The static impression test appears to depend upon fewer and simpler factors. The elastic properties of the material are almost entirely eliminated, the properties chiefly concerned being "strength" and "ductility."—S. L. A.

FURNACES AND FOUNDRY METHODS.

Durability of Lime-sand Brick.—Tests on the suitability of silica-lime building brick as a material for furnace construction are described by E. Damour.[*]

The material employed in the tests was a brick containing 78 per cent. of silica and 14 per cent. of lime, the balance being carbon dioxide and moisture. Small test bricks of this material were moulded and baked, and their loss of weight and resistance to crushing stress were measured after heating for two hours at constant temperatures, the range of temperature covered by the tests being from 50° C. to 1000° C.

Measurements of loss of weight indicate that dehydration of the lime in the brick is complete at about 550° C. Resistance to crushing forces was found to be only slightly affected by temperature up to 500° C. From 500° to 800° C. the strength decreases uniformly with rise in temperature, and at still higher temperatures cohesion is completely destroyed.

Experiments on deterioration, due to furnace gases, are also described, samples being exposed to the fumes in the furnace for periods of from two to sixty hours at temperatures of 300° or 400° C., the effect of such treatment on the test-pieces being again investigated by measurements of loss of weight and resistance to crushing.

It was found that, in all cases where the initial densities of the samples varied slightly, the best results were obtained with bricks of the higher densities. The deleterious effect of the furnace gases on the specimens is very clearly indicated, and is ascribed to the reaction of carbon dioxide with the lime in the brick. The experimental results of the tests are given in tabular form.

The author concludes that such material is quite unsuited for furnace and chimney construction, although statements to the contrary are not lacking.—D. E.

Electric Brass-melting Furnaces.—Particulars are given by G. H. Clamer [†] of recent progress in the application of the Hering electric furnace to the melting of metals and alloys. The furnace is of the resistance type, the heating current passing directly through the metal to be melted.

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[*] *Revue de Métallurgie*, 1914, No. 2, p. 203.
[†] *Metal Industry*, 1914, vol. vi. p. 105.

It is stated that the construction of the hearth, which carries the electrodes at the end of cylindrical holes, is such that the "pinch" effect which occurs when the current is passing serves to set up a very thorough circulation of the liquid metal, ensuring the even heating of the charge. A bath of the melted alloy is left on the hearth after pouring the furnace, and fresh cold metal is melted by immersion in this bath. Except when thus adding fresh metal, the furnace is kept closed, so that loss by oxidation is largely avoided, whilst a neutral or reducing atmosphere can be maintained in the furnace if desired.

Experiments with small furnaces of 25 to 30 kilowatt capacity have shown that yellow brass can be melted and superheated at the rate of about 8·7 lb. per kilowatt-hour. It is estimated that, with careful control, the cost of brass melting in this furnace should be about five-pence per 100 lb. of alloy, and it is stated that zinc losses are practically nil, there being an almost entire absence of white fume when melting down.

The furnace has also been successfully used for melting lead, iron, ferro-silicon, and even copper, in spite of the high conductivity of the last-named metal, the dimensions of the cylindrical heating holes in the hearth being modified according to the temperature required and the resistivity of the melt.—D. E.

Electric Furnaces. — Design, Characteristics, and Commercial Applications.—The design, characteristics, and application of electric furnaces are dealt with in a series of articles by W. M'A. Johnson and G. N. Sieger.* Considering first the electrodes, a much better principle of electrode design than that of current density is to keep the radiation surface constant per unit of current. The condition for minimum electrode loss is that when the temperature of the electrode is equal to that of the interior of the furnace, the electrode will abstract no heat from the furnace. Acheson graphite, moulded carbon and metals, such as copper or steel, are used as electrode material.

	Electrical Resistivity.	Thermal Resistivity.	Safe Carrying Capacity in Amperes per Square Inch.
	c.g.s.	c.g.s.	
Acheson graphite . . .	0·000813	6·18	125
Moulded carbon . . .	0·0038	61·8	38
Steel or iron	0·00000965	6·25	170
Copper	0·00000165	1·22	1000

Steel or copper electrodes are rarely used, save for the bottom electrode of a furnace having a bath of metal. They must be water-cooled.

Moulded carbon electrodes are made by mixing crushed petroleum coke

or anthracite slack, with tar as a binder, pouring, moulding, or extruding the hot mixture into the desired form and slowly heating to a white heat, whilst covered with sand to prevent oxidation.

Graphite electrodes are made by the Acheson process of subjecting moulded amorphous-carbon electrodes to a temperature of 2300° to 2500° C., sufficient to graphitize the carbon, in an electric furnace. The moulded electrodes are about one-third the price of the Acheson graphite. There is no great difference in resistance to oxidation between the two. The heat conductivity of the latter being higher, they are more resistant to sudden changes in temperature; they also machine better and are more likely to be free from hidden flaws. The best method of jointing round electrodes is by means of a cylindrical threaded plug screwed equal distances into each electrode. A number of small electrodes is better in a smelting furnace than one or two large ones. Electrode loss by oxidation in the case of moulded carbon and Acheson graphite is rarely more than 30 lb. per ton of primary raw material, and is often less than 10 lb. In the Siemens type of steel furnace the loss is often less than 25 lb. per ton of finished steel. Stub-end loss can be eliminated by using round electrodes jointed as above, which can be continuously fed in as required. For regular operation the stuffing boxes had best be built of special shape fire-brick or water-cooled metal (copper 95, zinc 4, tin 1 per cent., is recommended). A gas-tight joint is made by winding $\frac{1}{4}$-inch to $\frac{1}{3}$-inch asbestos rope about the electrode. Water-cooled bronze terminal connections (copper 85, zinc 5, tin 5 per cent.), with copper gauze between the terminal and the electrode, the whole clamped on and tightened by means of wedges, is recommended. Over-designing, from 5 to 10 amperes per square inch of contact surface, is advised.

Practice as regards tap-holes and stopping flow of slag is dealt with. Methods of construction of furnaces consisting of a refractory lining surrounded by brickwork, the whole bound together with iron stays, are considered in some detail and illustrated with sectional drawings. Probably the simplest way to allow for the expansion of the fire-brick structure on heating is by means of compression springs acting at the ends or in the middle of the iron tension members. Refractory materials are dealt with. The one in most general use, viz. ordinary fire-brick, consists essentially of silicate of alumina. Shapes and sizes are given. Magnesia, chrome, and silica brick, respectively basic, neutral and acid in character are more expensive, but give better results where high temperatures and special conditions are to be met. All have high coefficients of expansion. The linear expansion of fire-brick and of magnesia brick on heating to just over 1900° F. is 0·1 inch and 0·2 inch per foot respectively. The method of laying the brickwork is discussed. The manner of breaking joints in an arch, of covering over a flue on a small furnace without the use of an arch, and of laying a "Dutch arch," simple and cheap for spans up to 30 to 40 inches or even larger, is illustrated with sectional drawings. Water-cooling of the furnace walls is considered.

The character of building required for electric furnace work is discussed. Protection against fire is very necessary. Requisite foundations for furnaces of varying size and weight are given, accompanied by draw-

ings. With regard to power facilities, these should have 20 per cent. capacity in excess of the normal rating of the furnace. Voltage regulation is important. A 100,000-volt modern porcelain insulator would break down at 25 volts at 1400° C., and with such notable changes from perfect insulators to comparatively good conductors with change of temperature of the furnace, it is evident that voltage must be under good control. Voltage may be kept constant by automatic movement of the electrode up or down by a relay-controlled motor as in modern electric steel furnaces. When no such internal regulation is used external regulation must be arranged. Means of doing this are described.

Details of construction of some water-rheostats are given.

The cheapest way to convey current is by bus-bars bolted or clamped together. These bus-bars will carry at least 25 per cent. more than the same amount of copper in a bare cable. Connection to the electrodes is, of course, made by flexible cable suitably clamped on. A special cable for this, with core of asbestos rope and having almost perfect properties and characteristics, is made by the General Electric Company.—S. L. A.

Electrical Resistivity of Refractory Materials.—A method for determining the electrical resistivity of refractory materials, particularly at high temperatures, has been devised and is described by E. F. Northrup.* Results are given for alundum. That these measurements have not been made before is probably due to the fact that without special devices the difficulties in the way of making the measurements are insuperable. The method devised is easily applied and gives concordant results.

The refractory material is moulded into three thin rectangular plates, in the case of alundum 3·4 centimetres wide by 4·8 centimetres long by 0·25 centimetre thick. These are placed by side and separated from one another by two graphite slabs of length and width equal to those of the plates of refractory material, but of greater thickness—in this instance 0·8 centimetre. The whole is clamped centrally between two other graphite slabs of width and thickness equal to the two above mentioned, but of considerably greater length—in the present instance at least 25 centimetres. The clamping is effected by means of graphite screws passing between the long plates at their ends.

Electrical connection is made to each of the two short graphite slabs by means of leads of molybdenum wire 2 millimetres diameter, and screwed graphite plugs. The whole arrangement thus described is then inserted into a vertical tube-furnace and heated in an atmosphere of carbon monoxide. The furnace used in this instance was one specially designed by E. F. Northrup for the purpose.† The two molybdenum terminal wires passed up through a cylindrical cover-piece of baked lavite which tightly closed the top of the furnace.

Temperatures were measured by a Pt-PtRd couple enclosed in a Berlin porcelain jacket. Athough quite viscous at 1600° C., a casing of Berlin porcelain proves quite satisfactory, provided it does not come into contact with anything in the furnace.

* *Metallurgical and Chemical Engineering*, 1914, vol. xii. (No. 2), pp. 125-8.

As was expected, it was found impossible to make measurements of any accuracy using direct current, owing to the development of a back electromotive force, probably due to electrolysis of the refractory material. Results were obtained with ease and certainty, however, by using an electro-dynamometer method with alternating current.

Results for alundum, given in the form of a curve, show that whereas the resistivity is as high as 9×10^6 ohms at 20° C., it is as low as 190 ohms at 1600° C. The curve shows a point of inflection at 1100° C. —S. L. A.

High Temperature Electric Furnace for Temperatures up to 1700° to 1800° C.—A laboratory electric tube furnace for temperatures up to 1700° to 1800° C. of the carbon resistor type has been designed by E. F. Northrup,* who gives general particulars of its construction and capabilities.

The vertical tubular space available for heating purposes is 12 inches long by $1\frac{7}{8}$ inches diameter. The heater is a graphite tube resistor, cut in a special manner and mounted in a moulded refractory material surrounded by what amounts to a hermetically sealed casing of polished Monel metal, forming the outer walls of the furnace, the internal dimensions of which are $18\frac{1}{4}$ inches high by 13 inches diameter. The graphite heater-tube is protected from oxidation by an atmosphere of carbon monoxide developed from graphite which is not a part of the resistor. The two terminals of graphite project from the upper end of the tube at one side, and are covered with metal caps. They give no trouble and have a life longer than the heating unit itself. The refractory materials withstand a temperature of over 1800° C. and give at the same time the highest possible thermal insulation.

The furnace, which will operate on either direct or alternating current, is designed to work with a transformer of 4 kilowatt capacity and calls for a maximum of 170 amperes at 23 volts. The regulation of temperature is accomplished by the kilowatt input controlled by varying the number of turns in circuit on the primary of the transformer.

Electric furnaces may be constructed with little heat insulation, and a very high temperature be attained quickly with large power input, or they may have a large amount of heat insulation and the same high temperature be attained by the input of a small amount of energy continued over a long time. This furnace is of the latter type and heats and cools very slowly. With an input of 4 kilowatts platinum is melted in about 170 minutes. With 3 kilowatts copper is melted in about one hour, and nickel in 125 minutes. 1·6 kilowatts give a final temperature of 1260° C. and 2 kilowatts will finally melt nickel (1450° C.). The outside of the furnace never exceeds 200° C. when the interior is at the temperature of melting platinum.

The various parts of the furnace are all standard in size and easily and quickly interchangeable. At a conservative estimate the graphite resistor tubes may be heated to 1500° C. at least 40 to 50 times.

* *Metallurgical and Chemical Engineering*, 1914, vol. xii. (No. 1), pp. 31-3.

The furnace may be obtained through the Arthur H. Thomas Company of Philadelphia.—S. L. A.

History of Electric Furnaces.—A short summary of the history of the development of electric furnaces, accompanied by diagrammatic sketches, is given by W. M'A. Johnson and G. N. Sieger.* Prior to the practicalization of the dynamo by Edison, Siemens, and others, little could be attained by means of electric furnaces owing to the difficulty of obtaining sufficient power from primary batteries. Previous to 1876, therefore, we find little accomplished save of purely scientific interest. Davy in 1800 built a small "arc" furnace, and Henry at Princeton College had an electric furnace that was more than a scientific toy. Pepys in 1815 made some experiments. In 1849 Depretz made the original furnace of the "resistance" type. Edison in 1881 first exhibited the electric dynamo and motor. With the advent of the dynamo the practical stage of the electric furnace began.

In 1878 Siemens exhibited to the Royal Society of London a vertical "arc" furnace, the prototype of the Heroult steel-refining furnace, in which he melted several pounds of steel and boiled off several pounds of copper. He also exhibited a horizontal "arc" furnace. Following on these came the Heroult-Hall electrolytic furnace for production of aluminium, the Wilson carbide furnace, and then the slag-resistance or buried-arc type, in such common use in the manufacture of ferro-alloys.

In 1883 E. H. and A. H. Cowles developed the "resistance" type of furnace, in which a core of carbonaceous material in the charge itself carries the current in a horizontal direction. Their attempt to smelt copper-zinc ores by this method was, however, commercially unsuccessful. Moissan in 1890 performed his spectacular experiments in an arc furnace in which he concentrated upwards of 200 horse-power in a space of less than a cubic foot.

About this time the industrial limits of the electric furnace became recognized, and it was realized that electric heat could only be used for such purposes as its innate advantages gave it a metallurgical monopoly, as, for example, in the production of aluminium, where by its combined heating and electrolytic effect a metal originally selling for 5 dollars was reduced to a price of 50 cents per pound. Such useful products as calcium carbide, artificial graphite, and carborundum, need electric furnace temperatures for their manufacture. The harnessing of water power gave a large supply of energy and led to development of hydro-electric plants. In 1905 the production of ferro-silicon in the electric furnace became an important industrial success. Ferro-vanadium, chrome, molybdenum, and titanium followed. About this time the production of fine tool-steel in the electric furnace came into engineering prominence. The genius of Heroult developed the combined process of partial refining by fire processes with subsequent electric furnace treatment. There are few businesses which offer so great a profit with so little risk as does the manufacture of steel castings from cheap preheated scrap in the electric furnace.—S. L. A.

Improved Tammann Furnace.—The well-known Tammann laboratory furnace has been modified by U. Raydt,* who uses copper blocks in place of the former carbon and iron contact pieces. These blocks are perforated, and a stream of water is passed through them. The life of the carbon tube is greatly increased by this change.—C. H. D.

Melting-points of Refractory Oxides.—In a preliminary article, C. W. Kanolt † describes experiments to determine the melting-points of some refractory oxides by a heating-curve method. Temperatures were measured by a Morse optical pyrometer.

Some difficulty was encountered on account of the production of fumes, which caused the optical pyrometer to read too low. This was obviated by working in a high vacuum, or (in the case of lime and magnesia) in an atmosphere of inert gas.

Contamination of the test by the material used as a support was overcome by employing either graphite or tungsten supports according to circumstances, or by forming the material to be tested into a tube one end of which was supported in the colder end of the furnace.

						Melting-point.
Magnesia	.	.	.	.	.	2800° C.
Lime .	.	.	.	.	.	2572° C.
Alumina	.	.	.	.	.	2050° C.
Chromium oxide .	.	.	.	.	1990° C.

The melting-points of four oxides was found as above, the probable errors in temperature being not more than ± 0.3 per cent.—D. E.

New Type of Electric Furnace.—A new type of electric furnace for the reduction of ores is described by F. Louvrier.‡ The furnace is characterized by the use of electrodes which are practically fixed, and the regulation of temperature is accomplished by simple manipulation of switches, by means of which the number of electrodes in circuit or the position which they occupy towards one another can be varied.

The furnace proper consists of three principal parts, the shaft wherein the progressive heating of the charge takes place, the bosh which is the zone of reduction, and the crucible where the molten metal collects. The bottom of the furnace is conducting and connected to one of the phases of the current. A series of openings are horizontally disposed at various heights in the two opposite walls of the bosh, and through each of these openings passes a well-fitting electrode. These electrodes form two symmetric series opposite to each other. Each series corresponds to a phase of the current, and each electrode in the series can be connected with its corresponding phase by means of a switch. The electrodes are pushed through the openings into the furnace, so that they touch the charge without being immersed in it. The current passes through the charge between the two series of lateral electrodes, and between these

* *Zeitschrift für Elektrochemie*, 1914, vol. xx. p. 185.
† *Journal of the Franklin Institute*, vol. clxxvi. p. 587.
‡ *Metallurgical and Chemical Engineering*, 1913, vol. xi. (No. 12), pp. 711–13.

and the bottom electrode. The furnace is arranged in the same manner for use with single phase or continuous current.

The furnace has the advantages of simplicity of construction, ease of regulation, and uniformity of temperature, possibility of using high voltages (350 to 400 volts in large furnaces), and low electrode consumption. Details of construction and operation in the case of the smelting of iron, copper, lead, and zinc, together with sectional diagrams of the furnace are given.—S. L. A.

Refractories—Kieselguhr.—The mode of occurrence, nature, and properties of Kieselguhr are summarized by P. A. Boeck.* Some of the almost endless applications and uses of this material have long been known. The Greeks and Romans made the so-called " swimming brick," and the Emperor Justinian in A.D. 522 ordered the dome of the Hagia Sophia to be built of brick made of this material to lighten the weight of the structure.

Kieselguhr, a natural mineral, is formed by the accumulation of count-less myriads of the siliceous shells or casings of diatoms, one of the groups of flowerless aquatic plants which occur almost universally in all waters from arctic to torrid. These diatoms vary in size from that of a pin's head to such a minute size as only to be revealed by the highest powers of the microscope. The valves or shells are in many instances elaborately carved and ornamented with the most intricate and delicate designs of marvellous variety. Literally mountains of this siliceous material are found in California of a high degree of purity, containing up to 95 per cent. of silica. The material is the most effective inorganic thermal insulator known, which property has led to its extensive use for this purpose in the form of loose powder, solid natural blocks, burned insulating brick and tile, pipe covering, &c., for both high temperatures in furnaces, ovens, &c., and for low temperatures. The thermal conduc-tivity at 800° C. varies from 0·000315 gramme-calorie-second in the natural dried block to 0·000791 in the burned fire-brick. The fineness, together with the angularity, weakness, and low compressive strength of the skeletons of the diatoms, produce a material unsurpassed for polishing and burnishing objects without danger of scratching the surface of the softest metal. The melting-point of natural powdered Kieselguhr has been reported by the Bureau of Standards to be 1610° C., indicating its high refractory nature. Kieselguhr fire-brick is acid, highly refrac-tory, and a better insulator than any fire-brick now on the market. It is used for building and lining high-temperature furnaces, kilns, &c. The apparent density is 1·00. The Bureau of Standards reports the melting-point to be 1650° C. The crushing strength is approximately 1200 lb. per square inch.—S. L. A.

Refractory Cement.—It is stated † that a refractory furnace lining may be made from asbestos and water glass (sodium silicate) as below :

Fine asbestos	.	.	.	.	.	.	4 parts.
Water glass .	.	.	.	.	.	.	6 ,,

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* *Metallurgical and Chemical Engineering*, 1914, vol. xii. (No. 2), pp. 109–13.
† *Brass World*, 1913, vol. ix. p. 360.

The ingredients are mixed with water to form a paste, which is said to be superior to clay mixtures for patching and filling cracks.—D. E.

Test-bars for Non-ferrous Alloys.—Further experiments * on the most suitable castings for mechanical test-bars of alloys are described by V. Skillman.†

After a discussion of the relative merits of sand-cast test-bars attached to the work, and of chill castings poured in a separate metal mould, it is indicated that the adoption of chill cast test-bars is to be preferred, since more consistent results are obtained with chill cast bars, although the test specimens thus obtained will show better mechanical properties than the actual work itself, when this has been sand cast. It is pointed out that in any complicated casting, such as a motor car crank case, differences in the thickness of various parts of the casting must necessarily introduce variations in the rate of cooling, so that no matter how the accompanying test-bars be cast, whether in sand or chill moulds, they must be regarded as giving comparative figures rather than absolute values for the mechanical properties of the casting as a whole.

The shape of test-bar to be employed is also considered.

Experiments were made with different kinds of bronze, the alloys being cast into test-bars of nine varying patterns, and subsequently machined in most cases to standard test-bar sizes—2 inches long and 0·505 inch in diameter over the breaking section. Values are given for ductility and maximum stress relating to seven copper-tin alloys, containing varying quantities of lead, zinc, antimony, and phosphorus. These tables show very clearly that great differences in the tensile properties of a given alloy are to be obtained on altering the shape of test-bar employed; in the case of an alloy containing 89·15 per cent. of copper, 9·97 per cent. tin, 0·12 per cent. lead, and 0·41 per cent. phosphorus, the maximum stress is recorded as varying from 50,500 lb. per square inch to 18,500 lb. per square inch, according to the shape of test-bar employed. It may be doubted whether such very large differences in mechanical properties are to be attributed entirely to variations in the form of mould, but the results are fairly consistent amongst themselves, the highest values for maximum stress being always obtained for alloys cast in " pattern C "—an open iron mould giving a bar measuring two feet in length and one inch square. No particulars as to casting temperatures of the test-bars are given, but the castings were all made from regularly melted foundry heats of large quantities of alloy.—D. E.

Uniformity of Temperature in Furnaces.—Improvements in the laboratory electric furnace are described by A. W. Gray.‡ Two concentric heaters are used, consisting of nichrome ribbon wound longitudinally, instead of helically on iron pipes. Micabeston, a preparation of mica flakes and a resinous cement, is used for insulation. The

* See also *Journal of the Institute of Metals*, No. 1, 1913, vol. ix. p. 248.
† *Metal Industry*, 1914, vol. vi. p. 110.
‡ *Journal of the Washington Academy of Sciences*, 1914, vol. iv. p. 134.

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winding is non-inductive, and there is little danger of short-circuiting. With a furnace 30 cm. long, the mean temperature throughout the whole length has been found to be 0·37° lower than the temperature at the centre, the maximum drop at the extreme ends being 1°, when the mean temperature was 667° C. Without regulating the heating current, the temperature was only found to vary 0·067° in 20 minutes.—C. H. D.

Use of the Oxy-acetylene Torch in Foundries.—H. C Estep * states that the combustion of acetylene in a stream of oxygen in a properly constructed blowpipe forms sufficient heat to cut steel rapidly, and also to weld cast iron, steel, copper, aluminium and other metals by a true fusion process.

With all metals which oxidize at high temperatures, a flame having a slight excess of acetylene should be used, and a smaller amount of oxygen is required than for welding the same thickness of work in steel. In welding aluminium a flux is used to dissolve any oxide formed and to minimize oxidation.

As with cast iron, a preheating and an annealing after welding lessen the risks of injury by unequal expansions and contractions. With ductile metals the strains left in the vicinity of the weld are very slight, even if annealing be omitted.

A badly - cracked aluminium transmission case was welded in 30 minutes at a cost of 52 cents.

In welding brass castings, a manganese-bronze alloy rod is generally used for filling. This is fused by the flame, and forms a strong homogeneous weld answering all practical purposes.

There is a wider margin of profit in welding the non-ferrous metals and alloys which have a higher value than cast iron and steel, whilst the cost of welding is about the same. ·

In welding copper, oxidization is minimized by using a reducing flame, but the author does not point out the danger of doing this if the copper contains oxygen. Copper castings, however, are usually efficiently deoxidized. A flux is also used to protect the metal, and it consists of a mixture of potassium phosphate and potassium carbonate spread in a layer about ⅛ inch thick. This mixture fuses and forms a protective glaze under the application of the flame.

Repairing silicon-copper castings is described. The castings formed parts of acid-distilling apparatus, but were porous and leaky. As there were six or seven defective castings and their value was considerable, the oxy-acetylene process was adopted for effecting a remedy. Some of the castings were of rectangular box design, and each one contained two baffle trays cast solid with three sides of the casting, therefore preheating for the welding operation had to be carefully performed in order to prevent cracking. The welding was carried out while the castings were at a high temperature (uniform red heat) in a loose firebrick oven fired by an oil-burner. The castings were allowed to cool slowly with the oven after welding. Several heatings and weldings

* *The Iron Trade Review*, 1914, vol. liv. p. 243.

were necessary, owing to the fragility of the castings at the high temperatures prohibiting handling.

After welding was complete, the castings were subjected to hydrostatic pressure, and found to be water-tight.—F. J.

Vacuum Electric Furnace.—Improvements in this furnace are described by O. Ruff.* The furnace is of the carbon tube pattern, and at 2700° requires 900 amperes at 20 volts. A larger furnace has been constructed for use with alternating currents, with a heating tube 7·5 to 8 cm. inside diameter, consuming 30 to 35 kilowatts at 2000°.

Another pattern, horizontal instead of vertical, is described by O. Ruff.† The carbon tube heater is 30 cm. long, 2 cm. inside and 5 cm. outside diameter, and at 2850° requires 500 amperes at 30 volts.—C. H. D.

* *Zeitschrift für Elektrochemie*, 1914, vol. xx. p. 177.   † *Ibid.*, p. 1.

STATISTICS.

Algerian Mining in 1913.—The value of the mineral output of Algeria * in 1913 was £2,060,000, an increase of nearly 50 per cent. over the year 1910, when it amounted to £1,500,000. There are no smelting works in the country. The table given below shows the number of tons of minerals shipped for each metal:—

	1911.	1912.	1913.
Copper ores	4,939	316	2,299
Lead ores	60,895	84,495	82,085
Antimony ores	7,428	2,165	497
Mercury	...	...	10

British Columbia Mineral Output, 1912.—According to the *Annual Report of the Minister of Mines for British Columbia,*† the Mineral Production for 1912 was the greatest in the history of the Province, the total value of the output for the year being $32,440,800, an increase of $8,941,728 over that of 1911.

The output of copper was $8,408,513, which is 84 per cent. in excess of that for 1911.

The value of the gold output was $5,877,942, $5,322,442 of which represents lode mining and $555,500 placer mining, corresponding to increases of $596,929 and $129,500 respectively, as compared with 1911.

The output of silver was $1,810,045, an increase of $851,752 ; of lead $1,805,627, an increase of $736,106, and of zinc $316,139, an increase of $187,047 over the output for 1911.

British Columbia Mineral Output, 1913.—The British Columbia Bureau of Mines ‡ has published a preliminary review and estimate of the mineral production of the province for the year 1913.

The estimated production is as follows : gold, 266,547 ozs. ; silver, 3,569,642 ozs. ; lead, 54,205,594 lb. ; copper, 46,042,379 lb. ; zinc, 7,100,000 lb. ; coal, 2,136,694 tons ; coke, 285,123 tons.

* *Mining Journal*, vol. civ., No. 4097, p. 211.
† *Bulletin of the Imperial Institute*, 1913, vol. xi. No. 4, p. 669.
‡ *Canadian Mining Journal*, vol. xxxv. No. 3, p. 74.

The total value of the production for 1913 was $30,158,793, as compared with $32,440,800 in 1912. The production of gold, silver, lead, and zinc shows an increase, but the output of copper and coal was considerably smaller than in the previous year.

Californian Gold Production.—The mine production of gold in California in 1912 is reported by the U.S. Geological Survey * to have aggregated $19,713,478, a decrease of $23,430 from 1911.

The leading gold-producing countries in the year, and the values produced by each, were :—

Country.	Value in Dollars.
Amador	2,796,194
Luba	2,753,408
Butte	2,346,229
Nevada	2,081,958
Sacramento	1,712,587
Tuolumne	1,113,291

Canadian Mineral Production, 1912.—The annual report of John M'Leish,† containing revised figures for 1912, has been published by the Mines Branch, Ottawa.

The production of metalliferous products in 1912 was valued at $61,172,753, being 45·3 per cent. of the total mineral output. The value of non-metalliferous products was $45,080,674.

Federated Malay States Tin Output in 1913.—The output of tin from the above States in 1913 is given ‡ as 50,128 tons, as compared with 48,250 tons in 1912, and 43,967 tons in 1911.

French Manufacture of Aluminium.—A summary of the present status of the manufacture of aluminium in France is given in *La Revue Electrique*, 5th September 1913.§ Five French companies produce aluminium as follows :—

Société Electrométallurgique Française.—Dr. Paul Heroult's Company formed in 1888. Capital 15,500,000 francs. In the different plants of the Company at Froges la Praz, Saint-Michel-de-Maurienne, and L'Argentière (Briançon) 65,000 to 70,000 horse-power are available. Besides aluminium ingots, bar, wire, cable, tube, cooking utensils, and pure aluminium, the Company produces ferro-alloys, electric steel (Heroult process), and carbon electrodes.

Compagnie des Produits Chimiques d'Alais et de la Compargue.—Founded in 1855. Capital 10,500,000 francs. Its plant at Salindres (Gard), originally intended to manufacture soda by the Le Blanc process, was later devoted successfully to soda manufacture, and began in 1861 to produce aluminium by the purely chemical process of Sainte-Claire Deville. For thirty years it was the sole producer of aluminium.

* *Engineering and Mining Journal*, 1913, vol. 96, No. 19, p. 890.
† *Canadian Mining Journal*, 1913, vol. xxxiv. p. 661.
‡ *Board of Trade Journal*, 1913, vol. lxxxiv. p. 299.
§ *Metallurgical and Chemical Engineering*, 1913, vol. xi. (No. 11), p. 632.

Société de Produits Electrochimiques et Métallurgiques des Pyrénées.—
Founded in 1906, this Company has now a capital of 6,000,000 francs. Its
Auzat plant of 16,000 horse-power has a maximum output of 6 tons of
aluminium, 9 tons of chlorates or perchlorates, and 10 tons of calcium
carbide or ferro-alloys, per day.

Société des Forces Motrices et Usines de l'Arve.—Founded in 1895,
and has capital of 4,100,000 francs. Its Chedde plant of 22,000 horse-
power has a maximum output of 6 tons of aluminium and 20 tons of
chlorates or perchlorates per day.

Société d'Electro-Chimie.—Founded in 1889, and has a capital of
10,000,000 francs. In its numerous plants the Company produces
chlorates, aluminium, alumina, and calcium hydride, sodium, potassium,
and potassium cyanides, &c.

These five companies have formed another company, L'Aluminium
Français, which acts not only as sales agent, but is also intended to
carry out research work on the applications of aluminium. This Com-
pany also manufactures in its plants at Selzaete (Belgium) and Mennessis
(France) considerable quantities of alumina, sulphate of aluminium, &c.
It is now erecting at Arrean in the Pyrénées an aluminium factory, and
at Chembéry in Savoy a rolling mill for the manufacture of aluminium
sheet, &c. At Kremlin-Bicêtre, near Paris, it has a factory for the manu-
facture of tubes, &c.

German Production and Consumption of Metals in 1913.—
The *Frankfurter Zeitung* of 15th January 1914, reporting on the metal
market in 1913, states * that the world's copper production showed but a
slight increase over that of the previous year. In Germany the consump-
tion of copper in 1913 amounted to 276,714 metric tons, about 20,000
metric tons more than in 1912.

German lead consumption is given as 215,000 metric tons, a decrease
of 5500 metric tons on the figure for 1912. Zinc production in Germany
is estimated at 275,000 metric tons, or 8000 metric tons more than in
the previous year; whilst the tin industry, after opening badly, showed a
production for the year of 13,000 metric tons, a slight increase on the
figure for 1912. German consumption of this metal is given as 22,000
metric tons, also slightly above the corresponding value for the year
1912.

Gold Coast Gold Exports in 1913.—The Government *Gazette* † of
the Gold Coast states the exports of gold from that Colony in 1913 as
422,562 oz., value £1,625,878, as compared with 377,659 oz., value
£1,439,268 in 1912.

New Zealand Mineral Production in 1912.—The Trade Com-
missioner for New Zealand ‡ gives the following figures for its mineral
output in 1911 and 1912 :—

	1911.		1912.	
	Quantity.	Value.	Quantity.	Value.
Gold (ozs.)	455,226	£ 1,816,782	343,163	£ 1,345,131
Silver (ozs.)	1,311,043	131,587	801,165	84,739
Mixed metals (tons) . .	3,470	22,241	1,729	20,571
Coal (tons)	2,066,073	1,126,086	2,177,615	1,190,471
Coke (tons)	...	...	4	7
Total . . .	...	4,492,403	...	3,042,224

The decrease of nearly £500,000 is attributed to disastrous strikes, which lasted from May to November, on three of the principal mining fields.

Peruvian Minerals in 1912.—H.M. Minister at Lima reports * that the coal production of Peru dropped from 324,000 tons in 1911 to 268,000 tons in 1912. The Government is apparently prepared to encourage the development of the native coal deposits.

The production of silver in Peru in 1912 was valued at £1,058,860, and of copper £1,977,796, as compared with £626,713 and £1,411,416, the respective figures for 1911.

Prolongation of Zinc Syndicates.—It is announced † that, on the decision to prolong the International Zinc Works Union till April 1916, the German syndicate has followed suit, being prolonged till the same date.

Out of the total world's production of zinc in 1912 of 975,000 metric tons, 360,000 metric tons were controlled by the German syndicate and 580,000 by the International Syndicate.

Prussian Mineral Output, 1912.—The output of mining products in Prussia during 1911 and 1912 have now been officially reported,‡ and are given below, in metric tons :—

Ores of	1911.	1912.
Zinc	696,903	647,081
Lead	139,235	140,158
Copper	868,495	967,785
Nickel	9,609	12,113
Manganese	86,902	92,474
Arsenic	4,476	4,870
Pyrites	203,249	233,397

* *Board of Trade Journal*, 1913, vol. lxxxiii. p. 302.   † *Ibid.*, p. 700.
‡ *Engineering and Mining Journal*, 1914, No. 1, vol. 97, p. 14.

Prussian Mineral Production in 1912.—The output of some of the principal minerals from Prussia in 1912 are stated in an official report * of the Prussian Ministry of Commerce and Industry as under :—

	Quantity (Metric Tons).	Value (1000 Marks).
Coal	165,302,784	1,722,560
Lignite	65,803,959	130,468
Petroleum . . .	87,443	6,586
Zinc ore	647,081	52,238
Lead ore	140,158	19,155
Copper ore . . .	967,785	32,489
Manganese ore . .	92,474	1,168
Pyrites	233,397	2,214

Metric ton = 2204·6 lb. ; mark = 11·8d.

Russian Platinum Production, 1913.—The production of crude platinum in the Ural region of Russia in 1913 show a decrease, according to the official figures just published.† The total production was 299·45 poods, which is a decrease on 1912 of 37·775 poods. The table given below shows the production in troy ounces, for the last ten years. The figures are for crude metal, usually taken as 83 per cent. platinum.

1904 161,197	1909 164,513
1905 168,343	1910 176,020
1906 186,674	1911 185,529
1907 173,500	1912 177,515
1908 157,051	1913 157,630

Silesian Zinc Industry in 1913.—The *Börsen Zeitung* of 28th January 1914‡ gives the production of raw zinc in Upper Silesia during 1913 as practically the same as that of the previous year. Thus the state of the zinc industry is unsatisfactory ; this is attributed to the railway tariff disabilities on the large amounts of sulphuric acid produced as a bye-product in the zinc industry. In 1900 the production of sulphuric acid per ton of raw zinc was only 0·8 metric ton ; in 1913 it was 1·34 metric tons ; in view of this increase it is well that a reduction of railway rates for sulphuric acid is now in view. The production of sheet zinc in 1913 shows an increase of 5487 metric tons, or about 9·7 per cent. over that in 1912.

Metric ton = 2204·6 lbs.

South African Mineral Output.—The total output of gold in the Union of South Africa for the year 1913, as given by the Mines Department,§ was 8,798,712·773 fine ounces, value £37,374,553. Of

* *Board of Trade Journal*, 1913, vol. lxxxiii. p. 419.
† *Engineering and Mining Journal*, 1914, No. 12, vol. 97, p. 626.
‡ *Board of Trade Journal*, 1914, vol. lxxxiv. p. 417.
§ *South African Engineering*, 1914, vol. xxi., No. 2, p. 25.

this total the Witwatersrand contributed 8,424,950·9 fine ounces, value £35,786,915, and other districts in the Transvaal 373,384·719 fine ounces, value £1,586,032. The total output of the other provinces was 377·154 fine ounces, value £1,604. The Rhodesian output is not included in these figures, as Rhodesia is not in the Union of South Africa.

The output of silver was 952,596·814 fine ounces, value £115,822.

Swiss Aluminium Production.—In a report on the electro-chemical industries of Switzerland, R. Pitaval * states that that country, with abundance of water power, is hampered by the distance of the power stations from rivers or railways, most of the sources being in narrow and remote valleys.

During 1912 the price of aluminium has been increased. The new factory of the Neuhausen Company at Chippis has been working. A new outlet for the metal has been found in the manufacture of aluminium paper for wrapping chocolate, &c. This consumed 1200 tons of aluminium during the year, and its use is likely to increase. Forty-two square metres are obtained from 1 kilogram of the metal. The exportation of aluminium (ingots and worked products) was 85,710 metric quintals in 1912, against 38,032 in 1911.

United States Metal Production in 1913.—The figures given below for copper and lead refer only to metal produced from United States ore, but those for zinc include production from imported ore.†

Metal.	1912.	1913.
Copper (lb.)	1,241,762,508	1,228,811,581
Ferro-manganese (tons)	227,725	353,100
Gold (dollars)	93 451,500	88,301,023
Lead (tons of 2000 lb.)	410,006	433,476
Mercury (flasks of 75 lb. each) . .	25,147	*21,000
Silver (oz.)	63,766,800	67,601,111
Zinc (tons of 2000 lb.)	348,638	356,146
Arsenic (lb.)	5,852,000	4,624,140

* Estimated.

Victoria Mineral Output in 1912.—The Secretary of Mines for Victoria ‡ reports the total value of minerals raised in that State in 1912 as £2,331,294, as compared with £2,463,865 in 1911. The table below gives the production of some of the items for 1912 and for 1911 :—

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* *Journal du Four Electrique*, 1914, vol. xxiii. p. 578.
† *Engineering and Mining Journal*, 1914, vol. 97, p. 49.
‡ *Board of Trade Journal*, 1913, vol. lxxxiii. p. 199.

	Quantity.		Value.	
	1911.	1912.	1911.	1912.
			£	£
Gold (oz.)	504,000	480,131	2,140,855	2,039,464
Silver (oz.)	18,494	17,424	2,070	2,200
Coal (tons)	653,864	589,143	298,829	258,455
Tin ore (tons)	33	48	3,417	5,733
Antimony ore (tons) . . .	1,098	2,430	8,928	16,162
Wolfram (tons)	18	10	1,309	574
Magnesite (tons)	166	211	498	633

West Australian Mineral Production in 1912.—The Department of Mines of Western Australia * gives the following figures for the mineral output of that State during the year 1912 :—

	1911.		1912.	
	Quantity.	Value.	Quantity.	Value.
		£		£
Coal (tons) . . .	249,899	111,154	295,079	135,857
Copper ore (tons) . .	9,825	33,709	9,556	59,388
Copper ingot, matte, &c. (tons)	828	44,409	8	1,149
Gold (oz.) . . .	1,370,867	5,823,075	1,282,658	5,448,385
Silver (oz.) . . .	169,043	18,333	138,039	16,353
Lead ore (tons) . .	1,549	15,002	1,868	22,565
Pyritic ore (tons) . .	9,939	3,529	7,626	2,543
Tin ore and ingot (tons) .	495	55,220	575	70,578
Wolfram (tons) . .	9	826	...	...
Zinc, spelter, &c. (tons) .	12	189	14	217
Unenumerated . . .	...	407	...	3,172
Total . . .	...	6,105,853	...	5,760,207

World's Production of Copper.—The following table of statistics, compiled by Henry R. Merton & Co.,† shows the world's copper output, in English tons of fine copper, for the past three years :—

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* *Board of Trade Journal*, 1913, vol. lxxxiii. p. 251.
† *Mining Journal*, 1914, vol. cv. No. 4102, p. 329.

Country.	1911.	1912.	1913.
Africa—			
Katanga	1,000 ⎫	2,345 ⎫	6,790 ⎫
Cape Colony	4,480 ⎪ 16,980	3,870 ⎪ 16,370	3,220 ⎪ 22,510
Namaqua	2,500 ⎬	2,500 ⎬	2,500 ⎬
Sundries	9,000 ⎭	7,655 ⎭	10,000 ⎭
Argentina	1,020	330	115
Australasia	41,840	47,020	46,580
Austria	2,440	3,860	3,765
Bolivia	1,800	1,850	3,600
Canada	24,930	34,710	34,365
Chile	29,595	37,305	39,386
Cuba	3,695	4,325	3,365
England	400	300	*300
Germany—			
Mansfeld	20,520	20,180	19,980
Other German	1,490	5,040	4,930
Hungary	85	100	305
Italy	2,600	2,300	1,600
Japan	55,000	65,500	72,000
Mexico—			
Boleo	12,165	12,450	12,795
Other Mexican	†48,740	†60,005	†39,185
Newfoundland	1,155	540	...
Norway—			
Sulitelma	3,590	4,755	4,610
Other Norwegian	5,835	6,225	7,000
Peru	28,050	26,065	25,310
Russia	25,310	33,010	38,240
Servia	6,885	7,240	6,257
Sweden	2,000	1,500	1,000
Spain and Portugal—			
Rio Tinto	33,385 ⎫	39,925 ⎫	36,320 ⎫
Tharsis	3,395 ⎪	3,375 ⎪	3,220 ⎪
Mason and Barry	2,920 ⎬ 50,930	3,540 ⎬ 58,930	3,135 ⎬ 53,835
Sevilla	1,530 ⎪	1,390 ⎪	1,510 ⎪
Other Mines	9,700 ⎭	10,700 ⎭	9,650 ⎭
United States of America—			
Calumet and H.	†35,000 ⎫	†35,000 ⎫	†20,000 ⎫
Other Lake	†61,615 ⎪	†68,405 ⎪	†15,875 ⎪
Montana	†121,410 ⎬ 483,865	†138,055 ⎬ 554,360	†126,880 ⎬ 548,575
Arizona	†134,185 ⎪	†159,800 ⎪	†179,115 ⎪
Other States	†131,655 ⎭	†153,100 ⎭	†170,705 ⎭
Turkey	1,000	500	500
Venezuela	...	1,340	1,250
Total	871,920	1,006,110	986,375

| Average of Prices of Standard on 1st of each month | £68 5 9 | £73 1 3 | £55 16 2 |

The growth of the world's copper production during the fifteen years 1898–1912 is traced by J. B. C. Kershaw ‡ with the aid of statistics published by Messrs. H. R. Merton & Co., London. Taking the average price of bar copper during this period as £60 per ton, the aggregate

* Those marked with an asterisk are estimated.
† As given by the *Engineering and Mining Journal*, New York.
‡ *Metallurgical and Chemical Engineering*, 1913, vol. xi. (No. 11), pp. 617-619.

annual value of the world's output has increased from £15,480,000 in 1898 to £60,024,000 in 1912, an increase of nearly 400 per cent.—

Year.	World's Output in Tons.	Increase or Decrease.	Average Price per Ton.
			£ s. d.
1898	429,262	29,896	57 7 10
1899	472,244	42,618	72 10 6
1900	479,514	7,270	73 19 7
1901	516,628	37,114	67 17 3
1902	541,295	24,667	52 13 5
1903	574,775	33,480	57 18 8
1904	644,000	69,225	58 14 8
1905	682,125	38,125	69 2 6
1906	714,100	31,975	86 5 2
1907	713,965	−135	87 1 8
1908	754,180	40,215	60 0 6
1909	839,425	85,245	58 17 3
1910	864,275	24,850	57 3 2
1911	871,920	7,645	55 16 2
1912	1,004,485	132,565	73 1 3

In the above table the annual variations in total world's output are seen to have been very irregular, ranging from a decrease of 135 tons in 1907 to the enormous increase of 132,565 tons in 1912. The output has more than doubled during the period 1898–1912, and if present prices can be accepted as any criterion the demand for the red metal still grows.

The predominating position occupied and still maintained by the American mines is evident from the fact that the output from these mines was 234,271 tons in 1898 and 554,835 tons in 1912, representing 55 per cent.

The output of the other producing countries of the world in 1898 and in 1912 was as follows :—

	1898.	1912.
	Tons.	Tons.
Mexico	16,435	70,845
Japan	25,175	65,500
Portugal . . .	52,375	58,930
Australia . . .	18,000	47,020
Chili	24,850	37,305
Canada	8,040	34,710
Russia	6,260	33,010
Peru	3,040	27,165
Germany . . .	20,085	23,920
Africa	7,110	16,370
Norway	3,616	10,980
Servia * . . .	*	7,240

The price boom of 1898–1899 was due to the formation of the Amalgamated Copper Company in the States.

* 2140 tons in 1908.

World's Production of Zinc, 1913.—Messrs. Henry R. Merton and Company * have issued their statement of the production of zinc, or spelter, for the year 1913. The production for 1913 shows an increase of 28,360 tons, or 2·9 per cent. over the production for 1912, and over 1911 of 102,970 tons, or 11·6 per cent. The table below shows the production in long tons :—

	1911.	1912.	1913.
Belgium	192,020	197,045	194,590
Holland	22,375	23,555	23,940
Germany, East	153,715	166,425	167,440
Germany, West . . .	92,735	100,370	111,055
Great Britain	65,900	56,330	58,215
France and Spain . . .	63,210	71,025	69,905
Austria and Italy . . .	16,610	19,295	21,300
Poland	9,780	8,625	8,500
Norway	6,575	8,000	17,000
Total for Europe . .	622,920	650,670	671,945
Australia	1,700	2,260	3,665
United States . . .	263,280	309,560	315,240
Total	887,880	962,490	990,850

* *Engineering and Mining Journal*, 1914, vol. 97, No. 5, p. 295.

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> [In this new edition the author has succeeded admirably in bringing the information up to date by including the results of recent research and invention. These results are interpreted in such a way as to make them particularly acceptable to the practical man. The work includes chapters on the following : Properties of Alloys ; Methods of Investigation ; Constitution ; Influence of Temperature on Properties ; Corrosion of Alloys ; Copper Alloys, Brass, Bronzes, Special Brasses and Bronzes ; German Silver and Miscellaneous Copper Alloys ; White Metal Alloys ; Aluminium Alloys ; Silver and Gold Alloys ; Iron Alloys ; and Miscellaneous Alloys (Amalgams, &c.).]

LE CHATELIER, H. *La Silice et les Silicates.** 1914. $6\frac{3}{4}$ in. × $10\frac{1}{4}$ in. Pp. 574, 60 illustrations. Paris : A. Hermann et Fils. (Price Fr. 15.)

LEDEBUR, A. *Les laboratoires sidérurgiques.* Manuel pratique à l'usage des chimistes métallurgistes. Ninth edition, revised by W. Heike and translated from the German by M. Diamant and M. Coste. 1914. 8vo, pp. 224, with 26 illustrations. Paris : Dunod & Pinat. (Price 5s.)

LIEBIG, R. G. MAX. *Zink und Cadmium.* 16 × 23 centimetres. 598 pages (no index), 205 illustrations, 10 plates. Leipzig : Otto Spamer. (Price 32 marks.)

> [The book handles systematically, completely, and clearly every branch of the metallurgy of zinc.]

LUNGE, G., and E. BERL. *Tachenbuch für die Anorganisch-Chemische Grossindustrie.* 1914. Fifth edition. Pp. 305, with 15 figures in the text. Berlin : Julius Springer. (Price 8 M.)

MAIER, G. *Das Geld und sein Gebrauch.* Pp. 126. Leipzig, 1913 : B. G. Teubner. (Price 1s. 3d.)

MAKOWER, W., and H. GEIGER. *Practical Measurements in Radio-Activity.** $5\frac{3}{4}$ in. × $8\frac{3}{4}$ in. Pp. ix+151, illustrated with 61 figures. London : Longmans, Green, & Co. (Price 5s. net.)

> [This book is primarily intended as a laboratory course in radio-activity, but an attempt has also been made to meet the requirements of those engaged in original investigations. Tables of radio-active constants and of decay of different substances are given.]

MEGRAW, HERBERT A. *Details of Cyanide Practice.* 1914. 6 in. × 9 in. Pp. 215, fully illustrated. New York : McGraw-Hill Book Company. (Price 8s. 4d. net.)

MELLOR, J. W. *A Treatise on Quantitative Inorganic Analysis, with special reference to the Analysis of Clays, Silicates, and Related Minerals.* 1913. 8vo, pp. 778, with illustrations and plates. London : Charles Griffin and Co., Limited. (Price 30s.)

Metal Statistics, 1914.* Seventh Annual Edition, 1914. 6¼ in. × 4 in. Pp. 287. New York: American Metal Market Company. (Price 50 cents.)

> [The seventh annual edition contains the usual tables, and also certain additional ones. Statistics are given regarding: copper, tin, iron and steel, lead, spelter, aluminium, antimony, and silver; also miscellaneous tables for: gold production; production of secondary metals; metal duties; English-American price equivalents; metal prices in 1913; quicksilver prices, platinum prices, &c. &c.
>
> The book is practically complete in both the ferrous and non-ferrous metal fields.]

*Mexican Fuel Oil.** 1914. Pp. 150, illustrated. London: Anglo-American Petroleum Products Company, Limited. (Price 3s. 6d. net.)

> [The use of oil for heating purposes in connection with metallurgical processes is dealt with in Chapter VIII.]

MICHEL, J. *Travail des Métaux.* Nouvelle collection des recueils de Recettes rationelles. Pp. 356, with 153 illustrations. Paris: H. Desforges. (Price Fr. 5·75).

OSTWALD, WILHELM. *Outlines of General Chemistry.** Translated with the author's sanction by W. W. Taylor. Third edition. xvii + 596 pages. London: Macmillan and Company, Limited. (Price 17s. net.)

> [This is the third edition of Professor Ostwald's book, and has been translated from the fourth German edition of his work.
>
> The author, in revising the book, has borne in mind the reproach levelled against the previous edition of *Outlines*, that, in contrast with his other books, *Outlines* is "too difficult." These disadvantages have now been remedied to some extent.
>
> The whole book has been carefully revised, and several new chapters have been introduced, amongst which will be noted chapters on ions in gases, and radio-activity, and on colloids.]

PANCKE, E. *Legierungs-Metalle : Ihre Bestimmung und Kritische Beleuchtung der vorgeschlagenen Analysengänge nebst ihrer Verwendung.* 1913. 8vo, pp. 82. Halle a. S. : Wilhelm Knapp. (Price 4s. 6d.)

> [The metals which are considered with special attention to their alloys are tin, lead, antimony, copper, zinc, arsenic, bismuth, aluminium, nickel, cadmium, and mercury. A series of calculation tables is given at the end of the book.]

PANETH, F. *Ueber Kolloide Lösungen radioaktiver Substanzen,* 1913. 8vo, pp. 6. Wien : A. Holder. (Price 6d.)

PARK, J. *The Cyanide Process of Gold Extraction.* 1913. 5th English edition, revised and enlarged. Cr. 8vo, pp. 362. London: Charles Griffin & Co. (Price 8s. 6d.)

PHILLIPS, F. C. *Chemical German : An Introduction to the Study of German Chemical Literature. Including rules of nomenclature, exercises for practice, and a collection of extracts from the writings of German chemists and other scientists, and a vocabulary of German chemical terms and others used in technical literature.* 1913. 8vo, pp. 241. Easton, Pa.: The Chemical Publishing Company. (Price 8s. 4d.)

Power, F. Danvers. *A Pocket Book for Miners and Metallurgists.** 1914. Third edition, corrected. Pp. vi+371, with illustrations. London : Crosby, Lockwood, & Son. (Price 6s. net.)

[This, the third edition of this little work, should be found very useful by all those engaged in the Mining and Metal Industries. It comprises a multitude of rules, formulæ, tables, and notes for use in field and office work. The portion on " Assaying " has been entirely rewritten.]

Quin's Metal Handbook and Statistics, 1914.* Pp. 156. 4¼ in. × 6½ in. London : L. H. Quin. (Price 3s. 6d. net.)

[This pocket-book gives a large amount of information with regard to the leading metals. In addition there are daily price lists for the leading metals, and much useful miscellaneous information.]

Reinhardt, E. *Die Kupferversorgung Deutschlands und die Entwicklung der deutschen Kupferbörsen.* Pp. 108, with 2 plates. Bonn : A. Marcus and E. Webers Verlag. (Price 3s. 3d.)

Roscoe, H. E., and C. Schorlemmer. *Treatise on Chemistry.* Volume II.— The Metals. New edition (5th), completely revised by Rt. Hon. Sir Henry Roscoe and others. 1913. 4to, pp. xvi+1445, and 212 illustrations. London : Macmillan & Co. (Price 30s. net.)

[Amongst others, there are chapters on : Crystalline Form of Metals ; Colloidal Solutions of Metals ; Alloys and Amalgams ; Metallic Oxides, Hydroxides, and Salts ; Crystallography ; The Radio-active Elements, Radium, Actinium, Thorium, Uranium.]

Rutherford, E. *Radioaktive Substanzen und ihre Strahlungen.* Translated from English by Professor Marx, under the supervision of Professor Rutherford. 1914. Pp. 642. Leipzig : Akademische Verlagsgesell-schaft.

Sheppard, S. E. *Photo-Chemistry.* 1914. Pp. ix+446. Crown 8vo. Illustrated. London : Longmans, Green, & Co. (Price 12s. 6d. net.)

Sisley, G. E. *The Mining World Index of Current Literature, Vol. III.* First half-year 1913. Pp. xxvi+158. 8vo. Chicago : The Mining World Company. (Price $1·50.)

Skinner, Walter R. *The Mining Manual and Mining Year Book*, 1914. Pp. 1500. Demy 8vo. London : *Financial Times.* (Price 15s. net.)

Smith, E. F. *Elements of Electro-Chemistry.* Size 5¾ × 4 inches. Pp. 253. Philadelphia, Pa. : The John C. Winston Company. (Price 4s.)

Stansfield, Alfred A. *The Electric Furnace, its Construction, Operation, and Uses.** 1914. Second edition. Revised, enlarged, and reset. 6 in. × 9 in. Pp. 415, with 155 illustrations. London : The Hill Publishing Company, Limited. (Price 17s. net.)

[The development and use of electric furnaces has made such rapid strides during the past seven years, since the publication of the first edition of Professor Stansfield's book, that all interested in electric furnaces will welcome the second edition of this work, which has been doubled in size owing to the great advance

in the industry and the demand for more detailed treatment of the subject. The present edition covers not only the progress, but the essential, practical features of design, operation, and use of the electric furnace, and is filled with valuable data, drawings, and practical suggestions. There are fifteen chapters. The first is historical; four deal with the classification, efficiency, construction, and operation of electric furnaces; nine chapters treat with the various uses of the electric furnace, and in the last chapter an attempt has been made to indicate in which directions future developments of the electric furnace may be expected. The book is well got up in every way, and may be regarded as a standard work on the subject.]

STEWART, ALFRED W. *Chemistry and its Borderland.* 1914. Pp. xii+314, with 11 illustrations and two plates. London: Longmans, Green, and Co. (Price 5s. net.)

STIEGLITZ, J. *The Elements of Qualitative Chemical Analysis.* Volume I., Parts 1 and 2, pp. xi+312; Volume II., Parts 3 and 4, pp. viii+153. London: G. Bell & Sons, Limited. (Price 6s. net.)

THOMSON, Sir J. J. *Rays of Positive Electricity and their Application to Chemical Analysis.* 1913. Pp. 132. London: Longmans, Green, & Co. (Price 5s. net.)

THORPE, Sir EDWARD. *Dictionary of Applied Chemistry.** Revised and enlarged edition. In five volumes. Illustrated. London: Longmans, Green, & Co. (Price £2, 5s. per volume.)

[During the twenty-two years which have elapsed since the first volume of Thorpe's Dictionary was published, chemistry has made such rapid progress as hardly to be recognizable with its former self. It has, therefore, been necessary thoroughly to revise and enlarge the previous edition, and it is now issued in five large volumes, containing in all some 4390 pages.

Although termed a "Dictionary," it will be found to be more of an Encyclopædia, for many of the articles contained therein deal so extensively with the subjects on which they are written as to form small text-books on those subjects in themselves. Thus we find that there are 16 pages devoted to "Aluminium," 102 to "Analysis," 15 to "Assaying," 15 to "Copper," 40 pages to "Lead," and so on, each subject being well illustrated where necessary, and written by an eminent specialist on each subject.

The books are all well-printed, well-illustrated, and well-bound, leaving nothing to be desired. The information has been found, by constant use, to be thoroughly reliable, and the work is to be heartily recommended to, and will be found to be invaluable by, all those who are in search of an encyclopædia of the chemical and allied industries.]

TILDEN, Sir WILLIAM A. *The Progress of Scientific Chemistry in Our Own Times, with Bibliographical Notices.* Second edition. 1913. Pp. 366, including indices. London: Longmans, Green, & Co., Limited. (Price 7s. 6d. net.)

[This volume forms a very readable survey of the successive steps by which the system of theory generally accepted by chemists at the present day has been evolved.]

TREIBER, E. *Foundry Machinery.* Translated and revised from the German, and adapted to British practice, by Charles Salter. 7½ in. × 4¾ in. Pp. 135, 51 illustrations. London: Scott, Greenwood, & Co., Limited. (Price 3s. 6d. net.)

WADDELL, J. *Quantitative Analysis in Practice.* 1913. Pp. 162. Philadelphia : P. Blakiston's Sons, & Co. (Price 6s. 3d.)

[Deals with cement, limestone, clay, coal, copper, iron ore, lead ore, nickel and cobalt ore, zinc ore, bronze.]

WEED, WALTER HARVEY. *The Copper Handbook.* Volume XI., 1912–13. Houghton, Mich. : W. H. Weed. (Price $5.)

[A Manual of the Copper Mining industry of the World.]

WHITE, A. H. *Technical Gas and Fuel Analysis.* 1913. 8vo, 276 pages, with 47 illustrations. New York : McGraw-Hill Book Company. (Price $2.)

SECTION III.

MEMORANDUM AND ARTICLES OF ASSOCIATION AND LIST OF MEMBERS.

CONTENTS.

The Companies (Consolidation) Act, 1908

Memorandum of Association

OF

THE INSTITUTE OF METALS

1. The name of the Company is THE INSTITUTE OF METALS.

2. The Registered Office of the Association will be situate in England.

3. The objects for which the Association is established are :—

    (*a*) To take over the whole or any of the property and assets, which can be legally vested in the Association, and the liabilities and obligations of the unincorporated Society known as the Institute of Metals, and, with a view thereto, to enter into and carry into effect, with or without modifications, the agreement which has already been engrossed and is expressed to be made between Gilbert Shaw Scott of the one part, and the Association of the other part, a copy whereof has, for the purpose of identification, been signed by three of the subscribers hereto.

    (*b*) To promote the science and practice of non-ferrous metallurgy in all its branches, and to assist the progress of inventions likely to be useful to the members of the Association and to the community at large.

(c) To afford a means of communication between members of the non-ferrous metal trades upon matters bearing upon their respective manufactures other than questions connected with wages, management of works, and trade regulations.

(d) To facilitate the exchange of ideas between members of the Association and between members of the Association and the community at large by holding meetings and by the publication of literature, and in particular by the publication of a Journal dealing wholly or in part with the objects of the Association.

(e) To establish Branches of the Association either in the United Kingdom or abroad to be affiliated to the Association upon such terms and conditions as may be deemed advisable, but so that all such Branches shall prohibit the distribution of their income and property by way of dividend or otherwise amongst their members to an extent at least as great as is imposed on the Association by virtue of Clause 4 hereof.

(f) To acquire by purchase, taking on lease or otherwise, lands and buildings and all other property real and personal which the Association, for the purposes thereof, may from time to time think proper to acquire and which may lawfully be held by them, and to re-sell, under-lease, or sub-let, surrender, turn to account, or dispose of such property or any part thereof, and to erect upon any such land any building for the purposes of the Association, and to alter or add to any building erected upon such land.

(g) To invest and deal with the moneys of the Association not immediately required in such manner as may from time to time be determined.

(*h*) To borrow or raise or secure the payment of money in such manner as the Association shall think fit, and in particular by Mortgage or Charge upon any of the property of the Association (both present and future), and to redeem and pay off any such securities.

(*i*) To undertake and execute any trusts, the undertaking whereof may seem desirable.

(*k*) To establish and support, or aid in the establishment and support of associations, institutions, funds, trusts, and conveniences calculated to benefit employees or ex-employees of the Association or the dependents or connections of such persons, and to grant pensions and allowances and to make payments towards insurances, and to subscribe or guarantee money for charitable or benevolent objects or for any Exhibition or for any public, general, or useful object.

(*l*) To establish, form, and maintain a library and collection of metals, alloys, models, designs, and drawings, and other articles of interest in connection with the objects of the Association, or any of them.

(*m*) To give prizes or medals as rewards for research, for inventions of a specified character, or for improvements in the production or manufacture of non-ferrous metals and their alloys, and to expend money in researches and experiments, and in such other ways as may extend the knowledge of non-ferrous metals and their alloys.

(*n*) To do all things incidental or conducive to the attainment of the above objects or any of them.

Provided that the Association shall not support with its funds or endeavour to impose on or procure to be observed by its members any regulations which, if an object of the Association, would make it a Trade Union.

Provided also that in case the Association shall take or hold any property subject to the jurisdiction of the Charity Commissioners or Board of Education for England and Wales, the Association shall not sell, mortgage, charge, or lease the same without such authority, approval or consent as may be required by law, and as regards any such property the Council or Trustees of the Association shall be chargeable for such property as may come into their hands, and shall be answerable and accountable for their own acts, receipts, neglects, and defaults, and for the due administration of such property in the same manner and to the same extent as they would as such Council or as Trustees of the property of the Association have been if no incorporation had been effected, and the incorporation of the Association shall not diminish or impair any control or authority exercisable by the Chancery Division, the Charity Commissioners, or the Board of Education over such Council or Trustees, but they shall, as regards any such property, be subject jointly and separately to such control and authority as if the Association were not incorporated. In case the Association shall take or hold any property which may be subject to any trusts, the Association shall only deal with the same in such manner as allowed by law having regard to such trusts.

4. The income and property of the Association whencesoever derived shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly by way of dividend, bonus, or otherwise howsoever by way of profit, to the members of the Association. Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any member of the Association, in return for any services actually rendered to the Association, but so that no member of the Council or governing body of the Association shall be appointed to any salaried office of the Association or any office of the Association paid by fees, and that no remuneration or other benefit in money or money's worth shall be given to any

member of such Council or governing body except repayment of out of pocket expenses and interest at a rate not exceeding 5 per cent. per annum on money lent, or reasonable and proper rent for premises demised to the Association. Provided that this provision shall not apply to any payment to any railway, gas, electric lighting, water, cable, or telephone company of which a member of the Council or governing body may be a member, or any other company in which such member shall not hold more than one-hundredth part of the capital, and such member shall not be bound to account for any share of profits he may receive in respect of such payment.

5. The fourth paragraph of this Memorandum is a condition on which a license is granted by the Board of Trade to the Association in pursuance of Section 20 of the Companies (Consolidation) Act, 1908.

6. The liability of the members is limited.

7. Every member of the Association undertakes to contribute to the assets of the Association in the event of the same being wound up during the time that he is a member, or within one year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a member, and of the costs, charges, and expenses of winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding one pound.

8. If upon the winding-up or dissolution of the Association there remains, after satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the members of the Association, but shall be given or transferred to some other Institution or Institutions not formed or carrying on business for profit having objects similar to the objects of the Association, to be determined by the members of the Association at or before the time of dissolution, or in default thereof by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter, and if and so far as effect cannot

be given to the aforesaid provision, then to some charitable objects.

9. True accounts shall be kept of the sums of money received and expended by the Association, and the matter in respect of which such receipt and expenditure takes place, and of the property, credits, and liabilities of the Association, and, subject to any reasonable restrictions as to the time and manner of inspecting the same that may be imposed in accordance with the regulations of the Association for the time being, shall be open to the inspection of the members. Once at least in every year the accounts of the Association shall be examined and the correctness of the balance-sheet ascertained by one or more properly qualified auditor or auditors.

WE, the several persons whose names and addresses are subscribed, are desirous of being formed into an Association in pursuance of this Memorandum of Association.

NAMES, ADDRESSES, AND DESCRIPTIONS OF SUBSCRIBERS

GERARD ALBERT MUNTZ, French Walls, Birmingham, Baronet.
THOMAS TURNER, The University of Birmingham, Professor of Metallurgy.
ALFRED KIRBY HUNTINGTON, The University of London, Professor of Metallurgy.
WILLIAM H. JOHNSON, 24 Lever Street, Manchester, Iron Merchant and Manufacturer.
JAMES TAYLER MILTON, Lloyd's Register, E.C., Chief Engineer Surveyor.
ROBERT KAYE GRAY, Abbey Wood, Kent, Civil Engineer.
EMMANUEL RISTORI, 54 Parliament Street, London, S.W., Civil Engineer.
CECIL HENRY WILSON, Pitsmoor Road, Sheffield, Gold and Silver Refiner.
WILLIAM HENRY WHITE, 8 Victoria Street, Westminster, Naval Architect.
HENRY JOHN ORAM, Admiralty, London, S.W., Engineer Vice-Admiral.

Dated this 27th Day of July 1910.

Witness to the above signatures—

ARTHUR E. BURTON, Solicitor,
Hastings House, Norfolk Street,
Strand, W.C.

The Companies (Consolidation) Act, 1908

𝕬rticles of 𝕬ssociation

OF

THE INSTITUTE OF METALS

SECTION I.—CONSTITUTION

1. For the purposes of registration the number of members of the Association is to be taken to be 1000, but the Council may from time to time register an increase of members.

2. The subscribers to the Memorandum of Association and such other members as shall be admitted in accordance with these Articles, and none others, shall be members of the Association and shall be entered on the register of members accordingly.

3. Every person who was a member of the unincorporated Society known as the Institute of Metals on the day preceding the date of the incorporation of this Association, and who has not already become a member of this Association by virtue of having subscribed the Memorandum of Association thereof, shall be entitled to be admitted to membership of the Association upon writing his name in a book which has been provided for that purpose, or upon notifying in writing to the Association at its Registered Office his desire to become a member, and immediately upon the making of such entry or the receipt of such notice, shall be deemed to have been admitted and to have become a member of the Association and shall be placed upon the register of members accordingly, and thereupon any sums due and owing by such persons to the unincorporated Society shall immediately become due and payable by him to the Association.

4. Members of the Association shall be either Honorary Members, Fellows, Ordinary Members, or Student Members, and shall be respectively entitled to use the following abbreviated distinctive titles: Hon. Members, Hon. M.Inst.Met.; Fellows, F.Inst.Met.; Ordinary Members, M.Inst.Met.; and Students, S.Inst.Met.

5. *Honorary Members.*—It shall be within the province of the Council to elect not more than twelve honorary members, who shall be persons of distinction interested in or connected with the objects of the Association. Honorary Members shall not be eligible for election on the Council nor entitled to vote at meetings of the Association, and the provisions of Article 7 and Clause 7 of the Memorandum of Association shall not apply to such members.

Fellows shall be chosen by the Council, shall be limited in number to twelve, and shall be members of the Institute who have, in the opinion of the Council, rendered eminent service to the Association.

Ordinary Members shall be more than twenty-three years of age, and shall be persons occupying responsible positions. They shall be either (*a*) persons engaged in the manufacture, working, or use of non-ferrous metals and alloys; or (*b*) persons of scientific, technical, or literary attainments connected with or interested in the metal trades or with the application of non-ferrous metals and alloys.

Student Members shall be more than seventeen years of age, and shall not remain Student Members of the Association after they are twenty-five years of age, and shall be either (*a*) Students of Metallurgy; or (*b*) pupils or assistants of persons qualified for ordinary membership whether such persons are actually members of the Association or not. Student Members shall not be eligible for election on the Council nor entitled to vote at the meetings of the Association.

Section II.—ELECTION OF MEMBERS.

6. Save as hereinbefore provided, applications for membership shall be in writing in the form following marked " A,"

and such application must be signed by the applicant and not less than three members of the Association.

FORM A.

To the Secretary.

I, the undersigned,   , being of the required age and desirous of becoming a   Member of the Institute of Metals, agree that I will be governed by the regulations of the Association as they are now formed, or as they may be hereafter altered, and that I will advance the interests of the Association as far as may be in my power ; and we, the undersigned, from our personal knowledge, do hereby recommend him for election.

Name in full...

Address...

Business or Profession..

Qualifications..

Signature...

Dated this   day of   , 19   .

....⎫ Signatures
....⎬ of three
....⎭ Members.

7. Such applications for membership as Ordinary Members or Student Members as are approved by the Council shall be inserted in voting lists. These voting lists will constitute the ballot papers, and will specify the name, occupation, address, and proposers of each candidate. They shall be forwarded to the members for return to the Secretary at a fixed date, and four-fifths of the votes recorded shall be necessary for the election of any person.

Every such election shall be subject to the payment by the applicant of his entrance fee and first annual subscription, and he shall not become a member of the Association nor be entered on the Register of Members until such sums are actually received from him. In the event of his failing to pay such sums within the time specified in the notification to

him of his election, as provided in the next clause hereof, his election shall be void.

8. Upon election under the preceding Article the Secretary shall forward to the applicant so elected notice thereof in writing in the form following marked " B."

FORM B.

Sir,—I beg to inform you that on the　　　　　　　　　you were elected a　　　　Member of the Institute of Metals, subject to the payment by you of an entrance fee of £　　　　, and of your first annual subscription of £　　　　. These must be paid to me on or before the　　　day of　　　　19 , otherwise your election will become void.

I am, Sir, your obedient Servant,

....Secretary.

9. In the case of non-election, no mention thereof shall be made in the minutes.

Section III.—COUNCIL AND MODE OF ELECTION

10. The affairs of the Association shall be managed and conducted by a Council, which shall consist of a President, Past-Presidents, six Vice-Presidents, fifteen Members of Council, an Hon. Secretary or Hon. Secretaries, and an Hon. Treasurer. All members who have filled the office of President shall be, so long as they remain members of the Association, *ex officio* additional members of the Council under the title of Past-Presidents. The first members of the Council shall be the following:—President, Sir Gerard Muntz, Bart.; Vice-Presidents, Prof. H. C. H. Carpenter, Prof. W. Gowland, Prof. A. K. Huntington, Engineer Vice-Admiral H. J. Oram, Sir Henry A. Wiggin, Bart. Ordinary Members of Council, T. A. Bayliss, G. A. Boeddicker, Clive Cookson, J. Corfield, R. Kaye Gray, Summers Hunter, Dr. R. S. Hutton, E. Mills, J. T. Milton, G. H. Nisbett, E. Ristori, A. E. Seaton, Cecil H. Wilson, Prof. T. Turner (Hon. Treasurer), W. H. Johnson (Hon. Secretary).

11. Clauses 87, 89, 91, 92, 93, and 94 of the Table A in the First Schedule of the Companies (Consolidation) Act, 1908, shall apply to and form part of the Regulations of the Association, with the substitution of " Members of the Council " for " Directors " wherever in such clauses occurring.

12. The quorum for the transaction of business by the Council may be fixed by the Council, but shall not be less than five.

13. The first business of the Association shall be to acquire the property and assets, and to undertake the liabilities and obligations of the unincorporated Society known as the Institute of Metals, and for the purpose of so doing the Council shall forthwith take into consideration, and, if approved, adopt on behalf of the Association, the Agreement referred to in Clause 3 (*a*) of the Memorandum of Association.

14. The President shall be elected annually, and shall be eligible for re-election at the end of the first year, but shall not be eligible for re-election again until after an interval of at least two years.

15. Two Vice-Presidents and five Members of the Council, in rotation, shall retire annually, but shall be eligible for re-election. The members of the Council to retire in every year shall be those who have been longest in office since their last election, but as between persons who became members of the Council on the same day, those to retire shall (unless they otherwise agree among themselves) be determined by lot. In addition, those Vice-Presidents and Members of Council shall retire who have not attended any meeting of the Council or Association during the previous year, unless such non-attendance has been caused by special circumstances which shall have been duly notified to, and accepted by, the Council as sufficient explanation of absence.

16. At the Ordinary General Meeting preceding the Annual Meeting, the Council shall present a list of members nominated by them for election on the Council. Any ten members may also, at such Meeting, nominate a candidate other

than one of those nominated by the Council. A list of candidates so nominated shall be forwarded to each member of the Association, and must be returned by him to be received by the Secretary not later than seven days preceding the Annual Meeting.

17. A member may erase any name or names from the list so forwarded, but the number of names on the list, after such erasure, must not exceed the number to be elected to the respective offices as before enumerated. The lists which do not accord with these directions shall be rejected by the Scrutineers. The votes recorded for any member as President, shall, if he be not elected as such, count for him as Vice-President, and, if not elected as Vice-President, shall count for him as ordinary member of the Council. And the votes recorded for any member as Vice-President shall, if he be not elected as such, count for him as ordinary member of the Council.

18. The Council shall have power to appoint a member to fill up any vacancy that may occur in the Council during their year of office, but any person so appointed shall hold office only until the next following Ordinary General Meeting, and shall then be eligible for re-election.

Section IV.—DUTIES OF OFFICERS

19. The President shall be Chairman at all Meetings at which he shall be present, and in his absence one of the Vice-Presidents, to be elected, in case there shall be more than one present, by the Meeting. In the absence of a Vice-President, the members shall elect a Chairman for that Meeting.

20. An account shall be opened in the name of the Association with a Bank approved by the Council, into which all moneys belonging to or received by the Association shall be paid. All cheques on such account shall be signed by a member of the Council and countersigned by the Honorary

Treasurer. No account shall be paid before it has been certified as correct by the Council.

21. The Hon. Secretary or Secretaries shall be elected or appointed by the Council. He or they shall attend all Meetings, shall take minutes of the proceedings, shall be responsible for the safe custody of all papers, books, and other moveable property of the Association, and shall perform such other duties as may be prescribed by the Council from time to time. In particular, he or they shall be responsible for editing the *Journal of the Institute of Metals.*

The Council shall have power to appoint a paid Secretary or Secretaries, and to delegate to him or them all or any of the duties of the Hon. Secretary or Secretaries.

Section V.—GENERAL MEETINGS

22. The First General Meeting shall be held at such time, not being more than three months after the incorporation of the Association, and at such place as the Association may determine. Subsequent there shall be at least two General Meetings in each calendar year, one of which shall be held in London during the first three months of the calendar year, and the other at such time after the said Meeting to be held in London and in such locality as the Council may direct. The Meeting in London shall be the Annual General Meeting.

The quorum for a General Meeting shall be 10 members personally present.

23. The Council may convene an Extraordinary General Meeting for any special purpose whenever they consider it to be necessary. The Council shall convene an Extraordinary General Meeting for a special purpose, upon a requisition to that effect, signed by not less than twenty members. The business of such a Meeting shall be confined to the special subjects named in the notice convening the same. No member whose subscription is in arrear shall be entitled to debate or to vote at any General Meeting.

In case of equality of voting at any Meeting the Chairman shall have an additional or casting vote.

24. Seven days' notice at the least (exclusive of the day on which the notice is served or deemed to be served, but inclusive of the day for which notice is given) specifying the place, the day, and the hour of Meeting, and, in case of special business, the general nature of that business, shall be given in manner hereinafter mentioned, or in such other manner, if any, as may be prescribed by the members of the Association in General Meeting, to such persons as are, under the regulations of the Association, entitled to receive such notices from the Association, but the non-receipt of the notice by any member shall not invalidate the meeting.

25. A notice may be given by the Association to any member, either personally or by sending it by post to him to his registered address, or (if he has no registered address in the United Kingdom) to the address, if any, within the United Kingdom supplied by him to the Association for the giving of notices to him.

Where a notice is sent by post, service of the notice shall be deemed to be effected by properly addressing, prepaying, and posting a letter containing the notice, and a certificate of the Secretary or other Officer of the Association that such notice was so posted shall be sufficient proof of service. A notice so posted shall be deemed to have been served the day following that upon which it was posted.

26. If a member has no registered address in the United Kingdom, and has not supplied to the Association an address within the United Kingdom for the giving of notices to him, a notice addressed to him and advertised in a newspaper circulating in the neighbourhood of the registered office of the Association shall be deemed to be duly given to him on the day on which the advertisement appears.

27. Notice of every General Meeting shall be given in some manner hereinbefore authorised to every member of the Association, except those members who (having no registered

address within the United Kingdom) have not supplied to the Association an address within the United Kingdom for the giving of notices to them. No other persons shall be entitled to receive notices of General Meetings, but the Association may, but shall not be bound to give notice of General Meetings to members not entitled thereto in such manner as in the opinion of the Council may be practicable and convenient.

Section VI.—SUBSCRIPTIONS

28. The subscription of each ordinary member shall be two guineas per annum, and of each student member one guinea per annum. Ordinary members shall pay an entrance fee of two guineas each, and students an entrance fee of one guinea each. Provided that no entrance fee shall be required from any person who was a member of the unincorporated Society known as the Institute of Metals on the day preceding the Incorporation of this Association, and who had paid an entrance fee to the said Society. No entrance fee or subscription shall be payable in the case of Honorary members.

29. Subscriptions shall be payable in advance on July 1st in each year, save in the case of Ordinary Members and Student Members elected under Clauses 6 and 7 hereof, whose entrance fee and annual subscription shall become payable in accordance with the notification to them of their election. Every subscription shall cover the period down to the 30th of June next following, and no longer, and for this purpose any subscription paid to the unincorporated Society for the period of July 1st, 1909, to June 30th, 1910, by any person who becomes a member of this Association shall go and be in satisfaction of any payment due in respect of membership of this Association up to the 30th of June 1910.

30. Subject to the provisions of Clause 7 hereof, any member whose subscription shall be six months in arrear, shall forfeit temporarily all the privileges of the Association. Due notice in the Form following marked "C" shall be given to such member, and if such subscription remains

unpaid upon the date specified for payment in this notice, the Council may remove such member from the Register of Members of the Association, and thereupon any member whose name is so removed shall cease to be a member thereof, but shall nevertheless remain liable to the Association for such arrears.

FORM C.

Sir,—I am directed to inform you that your subscription to the Institute of Metals, due   , and amounting to £   , is in arrear, and that if the same be not paid to me on or before the   day of   , 19   , your name will be removed from the Register of Members of the Association.

I am, Sir, your obedient Servant,

....Secretary.

31. The Council may, in their discretion, and upon such terms as they think fit (including the payment of all arrears), accede to any application for reinstatement by a person whose name has been removed from the Register under the last preceding Clause hereof, and the name of any person so reinstated shall be placed upon the Register of Members accordingly.

The Council, in their discretion, may remove from the Register the name of any member who shall, in the opinion of the Council, be undesirable or unfit to remain a member after first giving him a reasonable opportunity of being heard, and thereupon he shall cease to be a member of the Association.

Section VII.—AUDIT

32. The provisions of the Companies (Consolidation) Act, 1908, as to Audit and Auditors shall apply to and be observed by the Association, the first General Meeting being treated as the Statutory Meeting, the Council being treated as the Directors, and the members being treated as the Shareholders mentioned in that Act.

Section VIII.—JOURNAL

33. The Journal of the Association may include one or more of the following :—

- (*a*) Communications made by members, students, or others.
- (*b*) Abstracts of papers appearing elsewhere.
- (*c*) Original papers appearing elsewhere.
- (*d*) Advertisements approved by the Council.

Every member shall be entitled to receive one copy of each issue of the Journal, delivered, post free, to his registered address.

Section IX.—COMMUNICATIONS

34. All communications shall be submitted to the Council, and those approved may be brought before the General Meetings. This approval by the Council shall not be taken as expressing an opinion on the statements made or the arguments used in such communications.

Section X.—PROPERTY OF THE ASSOCIATION

35. All communications so made shall be the property of the Association, and shall be published only in the Journal of the Association, or in such other manner as the Council may decide.

36. All books, drawings, communications, models, and the like shall be accessible to members of the Association, and the Council shall have power to deposit the same in such place or places as they may consider convenient for the members.

Section XI.—CONSULTING OFFICERS

37. The Council shall have power to appoint such consulting officers as may be thought desirable from time to time, and, subject to the provisions of Clause 4 of the Memorandum of Association, may vote them suitable remuneration.

Section XII.—INDEMNITY

38. Every member of Council, Secretary, or other officer or servant of the Association, shall be indemnified by the Association against, and it shall be the duty of the Council out of the funds of the Association to pay all costs, losses, and expenses which any such officer or servant may incur or become liable to by reason of any contract entered into or act or thing done by him as such officer or servant or in any way in the discharge of his duties, including travelling expenses.

Names, Addresses, and Descriptions of Subscribers

Gerard Albert Muntz, French Walls, Birmingham, Baronet.

Thomas Turner, The University of Birmingham, Professor of Metallurgy.

Alfred Kirby Huntington, The University of London, Professor of Metallurgy.

William H. Johnson, 24 Lever Street, Manchester, Iron Merchant and Manufacturer.

James Tayler Milton, Lloyd's Register, &c., Chief Engineer Surveyor.

Robert Kaye Gray, Abbey Wood, Kent, Civil Engineer.

Emmanuel Ristori, 54 Parliament Street, London, S.W., Civil Engineer.

Cecil Henry Wilson, Pitsmoor Road, Sheffield, Gold and Silver Refiner.

William Henry White, 8 Victoria Street, Westminster, Naval Architect.

Henry John Oram, Admiralty, London, S.W., Engineer Vice-Admiral.

Dated this 27th day of July 1910.

Witness to the above signatures—

Arthur E. Burton, Solicitor,

Hastings House, Norfolk Street,

Strand, W.C.

LIST OF MEMBERS

Members of Council are indicated by italics.
Original Members are those who were elected 1908–9.
† *Denotes Contributor of Paper.*

HONORARY MEMBERS

Elected Member.	
1910	GLAZEBROOK, RICHARD TETLEY, C.B., M.A., Sc.D., F.R.S., Director, The National Physical Laboratory, Teddington, Middlesex.
1912	LE CHATELIER, Professor HENRY, 75 Rue Notre Dame des Champs, Paris, France.
1910	NOBLE, Captain Sir ANDREW, Bart., K.C.B., D.L., D.C.L., Sc.D., F.R.S., 14 Pall Mall, S.W.

ORDINARY MEMBERS

1911	ABBOTT, ROBERT ROWELL, B.Sc. Peerless Motor Car Co., Cleveland, O., U.S.A.
1908–9	ADAMS, GEORGE, Strathblane, Forest Glade, Leytonstone, Essex.
1908–9	ADAMSON, JOSEPH, Oaklands, Hyde, Cheshire.
1908–9	AINSWORTH, GEORGE, The Hall, Consett, Durham.
1910	ALLAN, ANDREW, Jun., A. Allan & Son, 486 Greenwich Street, New York, U.S.A.
1908–9	ALLAN, JAMES McNEAL, Cammell, Laird & Company, Limited, Cyclops Works, Sheffield.
1908–9	ALLELY, WILLIAM SMITH, 3 Regent Street, Birmingham.
1908–9	ALLEN, JOHN HILL, 54 Westfield Road, Edgbaston, Birmingham.

Elected Member		
1912		ALLEN, THOMAS JAMES WIGLEY, German Silver Works, Spring Hill, Birmingham.
1908–9		ALLEN, WILLIAM HENRY, W. H. Allen, Son & Company, Limited, Queen's Engineering Works, Bedford.
1911		ANDERSON, FREDERIC ALFRED, B.Sc., Bank Chambers, 24 Grainger Street West, New- castle-on-Tyne.
1908–9	†	ANDREW, JOHN HAROLD, M.Sc., Victoria University, Manchester.
1910		ANDRI, ALFRED, General Manager, Fabrique Nationale d'Armes de Guerre, Herstal-près-Liége, Belgium.
1908–9		APPLETON, JOSEPH, Appleton & Howard, 12 Salisbury Street, St. Helens.
1911		APPLEYARD, ROLLO, 79 St. Mary's Mansions, Paddington, W.
1908–9		*ARCHBUTT, LEONARD,* *4 Madeley Street, Derby.*
1910		ASH, Engineer-Commander HAROLD EDWARD HAYDON, R.N., London and Glasgow Engineering Company, 172 Lancefield Street, Glasgow.
1912		ASH, PERCY CLAUDE MATCHWICK, 10 Broad Street, Golden Square, W.
1908–9		ASHOFF, WILHELM, Basse and Selve, Altena, Westphalia, Germany.
1908–9		ASTON, HENRY HOLLIS, Tennal House, Harborne, Birmingham.
1914		AYERS, Engineer-Capt. ROBERT BELL, M.V.O., R.N. (Rtd), 15 Infield Park, Barrow-in-Furness.
1908–9	†	BAILEY, GEORGE HERBERT, D.Sc., Ph.D., Edenmor, Kinlochleven, Argyll, N.B.
1908–9		BAIN, JAMES, The Cunard Engine Works, Huskisson Docks, Liverpool.
1908–9		BAKER, THOMAS, D.Sc., M.Met., "Westville," Doncaster Road, Rotherham.
1908–9		BAMFORD, CHARLES CLIFFORD, Winfields Rolling Mills, Limited, Cambridge Street, Birmingham.
1908–9	†	BANNISTER, CHARLES OLDEN, A.R.S.M., 60 West Side, Clapham Common, S.W.
1910		BARCLAY, ALEXANDER CLARK, Westholm, Jordanhill, Glasgow.

Elected Member.		
1908–9	†	BARCLAY, WILLIAM ROBB, 50 Upper Albert Road, Meersbrook, Sheffield.
1908–9		BARKER, JOHN HENRY, Birmingham Metal and Munitions Company, Ltd., Adderley Park Mills, Birmingham.
1908–9		BARNARD, ALFRED HENRY, H. B. Barnard & Sons, 148½ Fenchurch St., E.C.
1908–9		BARNARD, GEORGE, Callendar's Cable and Construction Company, Ltd., Cambridge Street, Birmingham.
1908–9		*BARR, Professor ARCHIBALD, D.Sc. (Glas.),* *Westerton, Milngavie, N.B.*
1908–9		BARWELL, CHARLES H., Barwells Ltd., Pickford Street, Birmingham.
1910		BASSETT, WILLIAM H., American Brass Co., Waterbury, Conn., U.S.A.
1908–9		BAWDEN, FREDERICK, Garston Copper Works, Liverpool.
1908–9		BAYLAY, WILLOUGHBY LAKE, Foremark, Dorridge, Warwickshire.
1908–9		*BAYLISS, THOMAS ABRAHAM,* *King's Norton Metal Co., Ltd., King's Norton, Bir-* *mingham.*
1908–9		BAYLISS, THOMAS RICHARD, Belmont, Northfield, Birmingham.
1908–9		BEAN, G., Allen Everitt & Sons, Ltd., Kingston Metal Works, Smethwick, Birmingham.
1908–9		BEARE, Professor T. HUDSON, B.A. (Adelaide), B.Sc. (Lond.), Engineering Laboratories, The University, Edinburgh.
1908–9		BECKER, PITT, 18/19 Fenchurch Street, E.C.
1908–9		BEDFORD, CHARLES YVONE RILAND, H. H. Vivian & Co., Ltd., Icknield Port Road, Birmingham.
1908–9		BEDSON, JOSEPH PHILLIPS, 137 Lapwing Lane, Didsbury, Manchester.
1913		BEER, EMIL, 120 Fenchurch Street, E.C.
1908–9		BEER, LUDWIG, Beer, Sondheimer & Co., Frankfurt-am-Main, Germany.
1910	†	*BEILBY, GEORGE THOMAS, LL.D., F.R.S.,* *11 University Gardens, Glasgow.*

Elected Member.		
1912		BELAIEW, Captain NICHOLAS T., 　　Chemical Laboratory, Michael Artillery Academy, 　　　St. Petersburg, Russia.
1908–9		BELL, Sir HUGH, Bart., D.L., D.C.L., LL.D., 　　Rounton Grange, Northallerton.
1908–9		BELL, THOMAS, 　　J. Brown & Co., Ltd., Clydebank, Dumbartonshire.
1911	†	BENEDICKS, Professor CARL AXEL FREDRIK, Ph.D., 　　Tegnérlunden 3^{iv}, Stockholm Va, Sweden.
1908–9	†	BENGOUGH, GUY DUNSTAN, M.A. (Cantab.), D.Sc. (Liv.), 　　The University, Liverpool.
1908–9		BENTON, ARTHUR, 　　Benton Brothers, Rodley Foundry, Sheffield.
1908–9		BEVIS, HENRY, 　　Pirelli, Limited, 144 Queen Victoria Street, E.C.
1910		BEVIS, RESTAL RATSEY, 　　" Hamptoune," Vyner Road, Birkenhead.
1908–9		BIBBY, JOHN HARTLEY, 　　John Bibby & Company (Garston), Limited, Garston 　　　Copper Works, Liverpool.
1908–9		BILES, Professor Sir JOHN HARVARD, Kt., LL.D., D.Sc., 　　10 University Gardens, Glasgow.
1908–9		BILL-GOZZARD, GEORGE, 　　Stephenson Chambers, 39A New Street, Birmingham.
1908–9		BILLINGTON, CHARLES, 　　" Heimath," Longport, Staffordshire.
1908–9		BIRCH, HARRY, 　　" Inglewood," Chester Road, Streetly, Birmingham.
1908–9		BLAIKLEY, ARTHUR, 　　10 Provost Road, South Hampstead, N.W.
1908–9		BLOOMER, FREDERICK JOHN, 　　" Penpont," Clydach, S.O., Glamorganshire.
1908–9		BLOUNT, BERTRAM, 　　76/78 York Street, Westminster, S.W.
1910		BLUNDELL, FREDERICK HEARN, 　　199 Wardour Street, W.
1908–9		*BOEDDICKER, GUSTAV ADOLF (Vice-President),* 　　*Henry Wiggin & Company, Limited, Wiggin Street* 　　　*Works, Birmingham.*
1912		BOLTON, EDWARD JOHN, 　　Thornbury Hall, Cheadle, Staffordshire.
1908–9		BOLTON, THOMAS, 　　T. Bolton & Sons, Limited., 57 Bishopsgate, E.C.
1912		BOOTE, EDGAR MIDDLETON, 　　2 Lithos Road, Hampstead, N.W.
1908–9		BOOTH, CUTHBERT RAYNER, 　　Jas. Booth & Co., Ltd., Sheepcote St., Birmingham.

Elected Member.	
1913	BORCHERS, Professor WILHELM, Dr.Ing., Dr.Ph., Ludwigsallee 15, Aachen, Germany.
1913	BOSCHERON, LOUIS, Hollogne-aux-Pierres, Belgium.
1911	BOWRAN, ROBERT, Robert Bowran & Company, Limited, 4 St. Nicholas' Buildings, Newcastle-on-Tyne.
1911	BOYLSTON, HERBERT MELVILLE, B.Sc., M.A., Sauveur & Boylston, Abbot Building, Harvard Square, Cambridge, Mass., U.S.A.
1908–9	BRABY, CYRUS, F. Braby & Co., Ltd., 110 Cannon Street, E.C.
1912	BRADLEY, BENJAMIN, Hedgefield, Harpenden, Herts.
1910	BRAIN, HENRY RICHARD, 55 Brockley Grove, Crofton Park, S.E.
1908–9	BRAY, DAVID, "Glenwood," Hardwick Road, Streetly, Birmingham.
1912	BREGOWSKY, IVAN M., Crane Company, 1214 Canal Street, Chicago, Ill., U.S.A.
1908–9	BROADFOOT, JAMES, Bull's Metal Company, Yoker, Glasgow.
1908–9	BROADFOOT, WILLIAM RITCHIE, John Broadfoot & Sons, Ltd., Inchholm Works, James Street, Whiteinch, Glasgow.
1908–9	BROCKBANK, JOHN GEORGE, 1 Cannon Street, Birmingham.
1910	BROOK, GEORGE BERNARD, "Cravenhurst," Fulwood, Sheffield.
1908–9	BROOKS, JOHN FREDERICK, Engineering Department, Municipal Technical School, Leicester.
1913	BROTHERHOOD, STANLEY, Peterborough.
1908–9	BROWN, CHARLES A. J., "Glenroy," Gillott Road, Edgbaston, Birmingham.
1910	BROWN, JAMES, Scotts' Shipbuilding and Engineering Company, Limited, Greenock.
1908–9	BROWN, ROBERT JOHN, W. Turner & Company, 75–79 Eyre Street, Sheffield.
1908–9	BROWN, WILLIAM, London Works, Renfrew.
1911	BROWN, WILLIAM MEIKLE, 46 Bede Burn Road, Jarrow-on-Tyne.

Elected Member.	
1911	BROWNE, Sir BENJAMIN CHAPMAN, Kt., Westacres, Newcastle-on-Tyne.
1908–9	BROWNSDON, HENRY WINDER, M.Sc., Ph.D., 109 Oxford Road, Moseley, Birmingham.
1913	BRYANT, CHARLES WILLIAM, Stanground House, Peterborough.

1908–9	BUCHANAN, CHARLES,
	    Lloyd's Register of British and Foreign Shipping,
	        71 Fenchurch Street, E.C.

1914	BUCK, HENRY ARTHUR,
	    "Malahide," Harrowdene Road, Wembley,
	        Middlesex.

1908–9	BUCKWELL, GEORGE WILLIAM,
	    Board of Trade Surveyors' Office, 73 Robertson
	        Street, Glasgow.

1911	BUELL, WILLIAM HEANEY, Ph.B.,
	    Winchester Repeating Arms Company, New Haven,
	        Conn., U.S.A.

1908–9	BULLEID, Professor CHARLES HENRY, M.A., University College, Nottingham.

1912	BURNER, ALFRED,
	    A. G. Mumford, Limited, Culver Street Engineering
	        Works, Colchester.

1913	BURNETT, JACOB EDWARD, 53 Percy Park, Tynemouth.
1913	BUTLER, REGINALD HENRY BRINTON, B.Sc., "Kirkbymead," Hermon Hill, S. Woodford, Essex.

1908–9	BUTTENSHAW, GEORGE ESKHOLME,
	    "Lynbrook," Wilbraham Road, Chorlton-cum-
	        Hardy, Lancashire.

1908–9	BUTTERFIELD, JOHN COPE, 79 Endlesham Road, Balham, S.W.
1908–9	CAIRD, PATRICK TENNANT, Belleaire, Greenock, Renfrewshire.
1908–9	CAIRD, ROBERT, LL.D., 56 Esplanade, Greenock, Renfrewshire.
1913	CALDWELL, ROBERT JOHN, D.Sc. (Lond.), "Rosendale," Holland Park, Belfast, Ireland.
1910	CAMPION, Professor ALFRED, The Royal Technical College, Glasgow.

1908–9	CANNING, THOMAS RICHARD,
	    W. Canning & Co., 133 Great Hampton Street,
	        Birmingham.

1911	CAPP, JOHN A.,
	    General Electric Company, Schenectady, N.Y.,
	        U.S.A.

Elected Member.		
1912		CARDOZO, HENRI ALEXANDRE, 54 Rue de Prony, Paris, France.
1910		CARELS, GASTON LOUIS, 53 Dock, Ghent, Belgium.
1913		CARNT, Engineer-Commander ALBERT JOHN, R.N., "St. Bedes," Walton, Peterborough.
1908–9		CARNT, EDWIN CHARLES, Westwood, Wootton Bridge, Isle of Wight.
1908–9	†	CARPENTER, *Professor* HENRY CORT HAROLD, *M.A.* *(Oxon.), Ph.D. (Leipzig), (Vice-President),* *Royal School of Mines, South Kensington, S.W.*
1908–9		CARR, JAMES JOHN WILLIAM, Charles Carr, Limited, Woodlands Bell and Brass Foundry, Smethwick, Birmingham.
1914		CARRUTHERS, Engineer-Commander DAVID JOHN, R.N., The Admiralty, Whitehall, Westminster, S.W.
1908–9		CARTER, ARTHUR, Brookfield Villa, Stalybridge, Manchester.
1914		CARTER, GEORGE JOHN, Cammell, Laird & Company, Limited, Birkenhead.
1908–9		CHALAS, EMILE CLAVEY, Chalas & Sons, Finsbury Pavement House, Fins- bury Pavement, E.C.
1908–9		CHAMBERS, DAVID MACDONALD, D. M. Chambers & Company, Norfolk House, Laurence Pountney Hill, Cannon Street, E.C.
1913		CHAPMAN, ARTHUR JENNER, F. Claudet, Limited, 6 and 7 Coleman Street, E.C.
1911		CHARPY, GEORGES, Directeur des Usines St. Jacques, Montluçon, France.
1908–9		CLAMER, GUILLIAM H., B.S., The Ajax Metal Company, Frankford Avenue, Philadelphia, Pa., U.S.A.
1908–9		CLARK, GEORGE, Richardsons, Westgarth & Company, Limited, Hartlepool.
1908–9		CLARK, HENRY, George Clark, Limited, Southwick Engine Works, Sunderland.
1908–9		CLARK, JOHN, British India Steam Navigation Company, Limited, 9 Throgmorton Avenue, E.C.
1914		CLARK, WILLIAM EDWARDS, "Newnham," Holly Lane, Erdington, Birmingham.
1913		CLARK, WILLIAM WALLACE, American Vanadium Company, Bridgeville, Pa., U.S.A.

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Elected Member.	
1914	CLARKE, WALTER G., 39 Old Broad Street, E.C.
1908–9	CLAYTON, GEORGE CHRISTOPHER, Ph.D., Croughton, near Chester.
1908–9	*CLEGHORN, ALEXANDER,* *14 Hatfield Drive, Kelvinside, Glasgow.*
1908–9	CLELAND, WILLIAM, B.Sc., Sheffield Testing Works, Blonk Street, Sheffield.
1908–9	COE, HARRY IVOR, M.Sc., The University, Edgbaston, Birmingham.
1908–9	COLLIE, CHARLES ALEXANDER, Earle, Bourne & Company, Limited, Lejonca, Bilbao, Spain.
1913	COLVER-GLAUERT, EDWARD, Dr.Ing., Brooklands, Osgathorpe, Sheffield.
1909	CONNOLLY, JAMES, Zuurfontein Foundry, Zuurfontein, Transvaal, South Africa.
1908–9	CONSTANTINE, EZEKIEL GRAYSON, 58 Victoria Street, Westminster, S.W.
1908–9	COOKSON, CLIVE, Cookson & Company, Limited, Milburn House, Newcastle-on-Tyne.
1908–9	CORFIELD, JOHN, Dillwyn & Company, Limited, Swansea.
1908–9	CORFIELD, REGINALD WILLIAM GODFREY, A.R.S.M., 5 Richmond Villas, Swansea.
1908–9	CORSE, WILLIAM MALCOLM, B.Sc., Secretary, American Institute of Metals, c/o Empire Smelting Company, Depew, N.Y., U.S.A.
1908–9	COURTMAN, ERNEST OWEN, A.R.S.M., Denford House, Atkins Road, Clapham Park, S.W.
1912	COWAN, GEORGE DUNFORD, Bridge House, Bridge Road, Millwall, E.
1908–9	COWPER-COLES, SHERARD OSBORN, " The Cottage," French Street, Sunbury-on-Thames.
1910	CRAWFORD, WILLIAM MITCHELL, 41 Kelvinside Gardens N., Glasgow.
1908–9	CRIGHTON, ROBERT, Harland & Wolff, Limited, Bootle, Liverpool.
1911	CROFTS, FREDERICK J., Bloomfield House, Tipton.
1908–9	CROSSLEY, PERCY BROADBENT, The Park, Ishapore, E.B.S. Railway, Nawabgunj, near Calcutta, India.

Elected Member.	
1908–9	CROWTHER, JAMES GUEST, 5 Sharrow Mount, Psalter Lane, Sheffield.

1911	CULLEN, WILLIAM HART,
	    Castner - Kellner Alkali Company, Limited,
	        Wallsend, Northumberland.

1911	DALE, ROBERT DAVIDSON, Cornwall Buildings, 45 Newhall Street, Birmingham.

1908–9	DANKS, AARON TURNER,
	    John Danks & Son, Proprietory, Limited, 391
	        Bourke Street, Melbourne, Victoria, Australia.

1909	DAVIES, PETER, Jun.,
	    W. Roberts & Company, Garston, Limited, Crown
	        Copper Mills, Garston, Liverpool.

1908–9	DAVISON, Captain HERBERT, 379 Upper Richmond Road, S.W.
1912	DAWLINGS, RICHARD MAURICE NEAVE, 85 Teignmouth Road, Brondesbury, N.W.

1910	DAWSON, WILLIAM FRANCIS,
	    The General Electric Company, West Lynn, Mass.,
	        U.S.A.

1908–9	DEER, GEORGE, Rio Tinto Company, Port Talbot, South Wales.

1908–9	DENDY, EDWARD EVERSHED,
	    Elliott's Metal Company, Limited, Selly · Oak,
	        Birmingham.

1908–9	DENNY, JAMES, Engine Works, Dumbarton.

1908–9 †	DESCH, CECIL HENRY, D.Sc. (Lond.), Ph.D. (Wurz.),
	    Metallurgical Chemistry Laboratory,
	        The University, Glasgow.

1914	DEWAR, JAMES McKIE,
	    Cammell, Laird & Company, Limited, 3 Central
	        Buildings, Westminster, S.W.

1911 †	DEWRANCE, JOHN, 165 Great Dover Street, S.E.
1908–9	DINGWALL, FREDERICK WILLIAM, 40 Chapel Street, Liverpool.
1913	DIXON, Engineer-Commander ROBERT BLAND, R.N., H.M. Dockyard, Portsmouth.
1908–9	DOBBS, ERNEST WALTER, 110 Holly Road, Handsworth, Birmingham.

1914	DONALDSON, THORNYCROFT,
	    J. I. Thornycroft & Company, Limited,
	        Southampton.

1908–9	DRURY, HARRY JAMES HUTCHISON, 4 Priorton Terrace, Swansea.

Elected Member.		
1908–9		DUFF, PHILIP JOHN, 42 Comely Bank Avenue, Edinburgh, Scotland.
1908–9		DUGARD, GEORGE HEATON, Dugard Brothers, Vulcan Mills, Birmingham.
1908–9		DUGARD, HERBERT ARTHUR, Dugard Brothers, Shadwell Street Mills, Birmingham.
1911		DUNCAN, HUGH MALCOLM, B.Sc., 5 King Edward's Road, Heaton, Newcastle-on-Tyne.
1908–9		DUNN, JOHN THOMAS, D.Sc. (Dur.), Public Analyst's Laboratory, 10 Dean Street, Newcastle-on-Tyne.
1911		DUNSMUIR, GEORGE AUGUSTUS, Dunsmuir & Jackson, Limited, Govan Engine Works, Govan, Glasgow.
1908–9		DYSON, WILLIAM HENRY, The Amalgams Company, Limited, Attercliffe Road, Sheffield.
1908–9		EARLE, JOHN WILLIAM, Heath Street South, Birmingham.
1908–9		ECCLES, ERNEST EDWARD, The British Aluminium Company, Ltd., Foyers, N.B.
1908–9	†	ECHEVARRI, JUAN THOMAS WOOD, 43 Merton Hall Road, Wimbledon, S.W.
1908–9		EDEN, CHARLES HAMILTON, Glynderwen, Blackpill, S.O., Glamorganshire.
1908–9		EDMISTON, JOHN ALEXANDER CLARK, 53 West Road, Irvine, Ayrshire.
1908–9	†	EDWARDS, Professor CHARLES ALFRED, D.Sc., The University, Manchester.
1908–9		EDWARDS, JOHN JAMES, Royal Laboratory, Royal Arsenal, Woolwich.
1908–9		ELLIS, HENRY DISNEY, 30 Blackheath Park, S.E.
1914		ELLIS, OWEN W., 115 Varna Road, Edgbaston, Birmingham.
1911		ELY, TALFOURD, India-rubber, Gutta-percha, and Telegraph Works Company, Limited, Silvertown, E.
1910		ENTHOVEN, HENRY JOHN, 153 Leadenhall Street, E.C.
1913		ESPIR, FERNAND, 3 East India Avenue, E.C.
1910		ESSLEMONT, ALFRED SHERWOOD, Orde House, Morpeth, Northumberland.

Elected Member.	
1908–9	EVANS, SAMUEL, M.Sc., Bradley Williams Ore Treatment Company (1910), Limited, Dunston Metal Works, Dunston-on-Tyne.
1914	EVANS, ULICK RICHARDSON, B.A., 28 Victoria Street, Westminster, S.W.
1911	EVERED, STANLEY, Evered & Company, Limited, Surrey Works, Smethwick, Birmingham.
1913	FALK, ERIK, Swedish Metal Works Company, Limited, Westerås, Sweden.
1908–9	FARLEY, DOUGLAS HENRY, Union Lane, Sheffield.
1911	FAY, HENRY, A.M., Ph.D., Mass. Institute of Technology, Boston, Mass., U.S.A.
1908–9	FÉRON, ALBERT, 49 Rue du Châtelain, Brussels, Belgium.
1911	FERRY, CHARLES, Bridgeport Brass Company, Bridgeport, Conn., U.S.A.
1908–9	FISHER, HENRY JUTSON, A. T. Becks & Company, 54 Clement Street, Birmingham.
1913	FITZ-BROWN, GEORGE, A.R.S.M., Ditton Copper Works, Widnes.
1914	FLEMINGER, REGINALD EDWARD, River Plate House, Finsbury Circus, E.C.
1911	FOERSTERLING, HANS, The Roessler and Hasslacher Chemical Company, Perth Amboy, N.J., U.S.A.
1911	FORSBERG, ERIK AUGUST, Aktiebolaget Separator, Fleminggatan 8, Stockholm, Sweden.
1910	FORSSTEDT, JAMES, Finspongs Metallverks, Aktiebolag, Finspong, Sweden.
1908–9	FRANCIS, ARTHUR AUBREY, 92/94 Gracechurch Street, E.C.
1908–9	FRANCIS, REGINALD, 92/94 Gracechurch Street, E.C.
1908–9	FRASER, KENNETH, The Yorkshire Copper Works, Limited, Pontefract Road, Leeds.
1908–9	FREY, J. HEINRICH, Zürich, Switzerland.

Elected Member.		
1908–9		GARDNER, HENRY,
		H. R. Merton & Company, Limited, Billiter Buildings, E.C.
1908–9		GARDNER, JAMES ALEXANDER,
		21 Cuthbert Place, Kilmarnock, Ayrshire.
1908–9		GARFIELD, ALEXANDER STANLEY, B.Sc.,
		10 Rue de Londres, Paris, France.
1912	†	GARLAND, HERBERT,
		P.O. Box 417, Cairo, Egypt.
1908–9		GARNHAM, FREDERICK MALCOLM,
		8 West Bank, Stamford Hill, N.
1908–9		GARNHAM, JAMES COOTE,
		132 Upper Thames Street, E.C.
1912		GARRETT-SMITH, NOEL,
		Edison & Swan United Electric Light Company, Limited, Ponder's End, Middlesex.
1908–9		GAYWOOD, CHARLES FREDERICK,
		Sydney Cottage, Durham Road, Sparkhill, Birmingham.
1912		GEM, EVELYN PERCY,
		George Johnson & Company, Montgomery Street, Sparkbrook, Birmingham.
1914		GIBB, ALLAN, A.R.S.M.,
		29 Buckingham Palace Mansions, S.W.
1911		GIBB, MAURICE SYLVESTER,
		Central Marine Engine Works, West Hartlepool.
1908–9		GIBBINS, WILLIAM WATERHOUSE, M.A.,
		Selly Oak, Birmingham.
1908–9		GIBBONS, WILLIAM GREGORY,
		"Viewpark," Russell Place, Trinity, Edinburgh.
1913		GIBBS, LEONARD,
		"Abermaw," School Road, Hall Green, Birmingham.
1908–9		GILCHRIST, JAMES,
		Stobcross Engine Works, Glasgow.
1910		GILLETT, HORACE W., A.B., Ph.D.,
		Morse Hall, Ithaca, New York, U.S.A.
1914		GILLEY, THOMAS BARTER,
		The Metallurgical Company, Limited, Newcastle-on-Tyne.
1910		GIRDWOOD, ROBERT WALKER,
		Wm. Gallimore & Sons, Arundel Works, Sheffield.
1908–9		GIRTIN, THOMAS, M.A.,
		H. L. Raphael's Refinery, 48 Thomas Street, Limehouse, E.
1913		GLADITZ, CHARLES,
		Duram Works, Hanwell, W.

Elected Member.		
1908–9		GOLDSCHMIDT, Professor HANS, Ph.D., Th. Goldschmidt Chemical and Tin Smelting Works, Essen-Ruhr, Germany.
1908–9		GOODWIN, Engineer-Rear-Admiral GEORGE GOODWIN, R.N., C.B., "Meadowside," 91 Thurleigh Road, Wandsworth Common, S.W.
1912		GORDON, JOSEPH GORDON, 15 Queen Anne's Mansions, S.W.
1908–9		GOWER, FRANCIS WILLIAM, The Birmingham Aluminium Casting (1903) Company, Limited, Cambridge Street, Birmingham.
1908–9	†	*GOWLAND, Professor WILLIAM, F.R.S., A.R.S.M. (Past-President),* 13 *Russell Road, Kensington, W.*
1908–9		GRACIE, ALEXANDER, M.V.O., Fairfield Works, Govan, Glasgow.
1912		GRAHAM, ALFRED HENRY IRVINE, Fuller's Cottage, Ditton Road, Surbiton.
1910		GRAZEBROOK, Engineer-Lieutenant ROBERT, R.N., The Admiralty, Whitehall, Westminster, S.W.
1908–9	†	GREENWOOD, HERBERT WILLIAM, The Boundary Chemical Company, Limited, Cranmer Street, Liverpool.
1908–9		GREENWOOD, THOMAS, Rosegarth, Ilkley, Yorkshire.
1910		GREENWOOD, VLADIMIR EDWARD, (*Address missing.*)
1908–9		GREER, HENRY HOLME AIREY, James C. Greer & Son, 50 Wellington Street, Glasgow.
1910		GREGORY, SEWELL HARDING, 120 Coleherne Court, S.W.
1908–9		GRICE, EDWIN, 5 Beach Mansions, Southsea, Hampshire.
1908–9		GRIFFITHS, HAROLD, The New Delaville Spelter Company, Limited, Spring Hill, Birmingham.
1909		GRIMSTON, FRANCIS SYLVESTER, Hawksdale, Naini Tal, Upper India.
1912		GROVES, CLARENCE RICHARD, M.Sc., Gamble Institute, St. Helens, Lancashire.
1913		GUERNSEY, The Rt. Hon. LORD, 9 Sussex Square, W.
1911	†	GUERTLER, WILLIAM MINOT, Ph.D., Kunz-Buntschuh-Str. 7B, Berlin-Grunewald, Germany.

Elected Member.		
1912		GUESS, Professor GEORGE A., Oakville, Ontario, Canada.
1908–9		GUILLEMIN, GEORGES, 16 Rue du Sommerard, Paris (5ᵉ), France.
1908–9		GUILLET, Professor LÉON, 8 Avenue des Ternes, Paris, France.
1908–9	†	GULLIVER, GILBERT HENRY, B.Sc., 99 Southwark Street, S.E.
1908–9		GWYER, ALFRED GEORGE COOPER, B.Sc. (Lond.), Ph.D. (Gott.). The British Aluminium Company, Limited, Milton, Staffordshire.
1914		GWYNNE, NEVILL G., Gwynnes, Limited, Hammersmith Ironworks, W.
1910		HADDOCK, WALTER THORPE, The Heeley Silver-Rolling and Wire Mills, Ltd., Sheffield.
1908–9		HADFIELD, Sir ROBERT ABBOTT, Kt., D.Sc., D.Met., F.R.S., 22 Carlton House Terrace, S.W.
1908–9		HALL, HENRY PLATT, Platt Brothers and Company, Limited, Oldham.
1908–9		HALL-BROWN, EBENEZER, Richardsons, Westgarth & Co., Ltd., Middlesbrough.
1908–9		HALLETT, JOSEPH, 70 Fenchurch Street, E.C.
1914		HAM, Engineer-Captain JOHN WILLIAM, R.N., 28 Telford Avenue, Streatham Hill, S.W.
1908–9		HAMILTON, GERARD MONTAGUE, Calle Chicarreros 10, Sevilla, Spain.
1911		HANKINSON, ALFRED, Richard Johnson, Clapham & Morris, Limited, P.O. Box 1102, Sydney, Australia.
1911		HANNA, ROBERT WALKER, 4 Birch Terrace, Dickenson Road, Rusholme, Manchester.
1911		HANNA, WILLIAM GEORGE, 4 Birch Terrace, Dickenson Road, Rusholme, Manchester.
1908–9		HARBORD, FRANK WILLIAM, A.R.S.M., 16 Victoria Street, Westminster, S.W.
1908–9		HARLOW, BERNARD SCHÄFFER, Robert Harlow & Son, Heaton Norris, Stockport.
1914		HARRIS, JONATHAN WISTAR, B.S., Western Electric Company, 463 West Street, New York, N.Y., U.S.A.

Elected Member.	
1911	HARRIS, THOMAS ROBERT, 2 Calverley Villas, Dawley Road, Harlington, Middlesex.
1911	HARRISON, JOHN SAMUEL, "Llanberis," Chester Road, near Erdington, Birmingham.
1908–9	HARTLEY, RICHARD FREDERICK, B.Sc. (Glas.), Royal Laboratory, Royal Arsenal, Woolwich.
1911 †	HAUGHTON, JOHN LESLIE, M.Sc., "Oakhurst," Thicket Road, Sutton, Surrey.
1908–9	HEAP, JOHN HENRY, The British Mining and Metal Company, Limited, 123–127 Cannon Street, E.C.
1908–9	HEAP, RAY DOUGLAS THEODORE, Kingsway House, Kingsway, London, W.C.
1908–9	HEATHCOTE, HENRY LEONARD, B.Sc., Rudge-Whitworth, Limited, Coventry.
1908–9	HEBERLEIN, FERDINAND, Bockenheimer Anlage 45, Frankfurt-am-Main, Germany.
1908–9	HECKFORD, ARTHUR EGERTON, Birmingham Metal Works, Frederick Street, Birmingham.
1911	HENDRY, Colonel PATRICK WILLIAM, Chairman, Hendry Brothers, Limited, 32 Robertson Street, Glasgow.
1908–9	HERDSMAN, WILLIAM HENRY, 22 Newlands Park, Sydenham, S.E.
1912	HEUSLER, FRIEDRICH, Ph.D., Isabellen-Hütte, Dillenburg (Hessen-Nassau), Germany.
1911	HEWITT, Professor JOHN THEODORE, M.A. (Cantab.), D.Sc. (Lond.), Ph.D. (Heid.), F.R.S., Clifford House, Bedfont, Middlesex.
1908–9	HEYCOCK, CHARLES THOMAS, M.A., F.R.S., 3 St. Peter's Terrace, Cambridge.
1914	HIGGS, CLAUDE, 3 Museum Mansions, Great Russell Street, W.C.
1908–9	HIGHTON, DOUGLAS CLIFFORD, M.A., Highton & Son, Limited, Brassfounders and Engineers, 20 Graham Street, City Road, N.
1914	HILL, EUSTACE CAREY, Clifton House, Park Road, Coventry.
1911	HILL, ERNEST HENRY, 13 East Grove Road, Sheffield.
1908–9	HILLS, CHARLES HAROLD, B.Sc., 5 Windsor Crescent, Newcastle-on-Tyne.

Elected Member.		
1908–9		HIRST, TOM GREENOUGH, 49 Union Street, Leigh, Lancashire.
1911		HOBSON, ARTHUR E., International Silver Company, Meriden, Conn., U.S.A.
1908–9		HODGKINSON, Professor WILLIAM RICHARD E., M.A., Ph.D. (Würz.), 89 Shooter's Hill Road, Blackheath, S.E.
1908–9		HOFMAN, Professor HEINRICH OSCAR, Ph.D. (Ohio), Institute of Technology, Boston, Mass., U.S.A.
1911		HOGG, THOMAS WILLIAMS, John Spencer & Sons, Ltd., Newburn Steel Works, near Newcastle-on-Tyne.
1908–9		HOLLOWAY, GEORGE THOMAS, 9–13 Emmett Street, Limehouse, E.
1908–9		HOLMES, JOSEPH, Welsh Tinplate and Metal Stamping Company, Limited, Brondeg, Llanelly, South Wales.
1908–9		HOLT, HAROLD, E. Kempster & Sons, Borough Brass Works, Bury, Lancashire.
1912		HOLT, THOMAS WILLIAM, 103 Wakefield Road, Stalybridge, Manchester.
1910		HOOD, JAMES MACLAY, " Rowallan," Maryland Drive, Glasgow, S.W.
1908–9		HOOTON, ARTHUR J. S., S. H. Johnson & Company, Limited, Engineering Works, Carpenter's Road, Stratford, E.
1908–9		HOPKINS, SUWARROW MOORE, Birmingham Battery and Metal Company, Ltd., Selly Oak, Birmingham.
1908–9		HOPKINSON, FRANK ADDY, Chairman, J. Hopkinson & Company, Limited, Britannia Works, Huddersfield.
1908–9		HOWE, Professor HENRY MARION, A.M., B.Sc., LL.D. (Harv. and Lafayette), Broad Brook Road, Bedford Hills, N.Y., U.S.A.
1913	†	HOYT, Professor SAMUEL LESLIE, School of Mines, University of Minnesota, Minneapolis, Minn., U.S.A.
1908–9	†	HUDSON, OSWALD FREEMAN, M.Sc., The University, Edgbaston, Birmingham.
1910	†	*HUGHES, GEORGE,* *Lancashire and Yorkshire Railway Works, Horwich, Lancashire.*
1908–9		HUGHES, GEORGE FREDERICK, Box 23, Pietersburg, Transvaal, South Africa.

Elected Member.		
1908–9		HUGHES, JOSEPH, Albion Metal Works, Woodcock Street, Birmingham.
1908–9	†	HUGHES, THEOPHILUS VAUGHAN, A.R.S.M., 130 Edmund Street, Birmingham.

1912		HULL, DANIEL RAYMOND,
		    American Brass Company, Kenosha, Wisconsin,
		        U.S.A.

1908–9	†	HUMPHRIES, HENRY JAMES,
		    Atlas Metal and Alloys Company, 52 Queen Victoria
		        Street, E.C.

1908–9		HUNTER, GEORGE BURTON, D.Sc. (Dur.), Wallsend-on-Tyne.
1908–9		*HUNTER, SUMMERS (Vice-President),* *1 Manor Terrace, Tynemouth, Northumberland.*

1908–9	†	*HUNTINGTON, Professor ALFRED KIRBY, A.R.S.M. (Past-*
		    President),
		    Metallurgical Laboratories, King's College, London.

1908–9		HURBURGH, LEONARD HENRY, W. F. Dennis & Co., 49 Queen Victoria Street, E.C.
1908–9		HURREN, FREDERICK HAROLD, 25 Spencer Avenue, Coventry.
1908–9		HUSSEY, ARTHUR VIVIAN, Dolgarrog Works, Tal-y-cafn, North Wales.
1908–9		*HUTTON, ROBERT SALMON, D.Sc.,* *William Hutton & Sons, Limited, Sheffield.*
1908–9		HYMAN, WALTER, I. & J. Hyman, Thornhill Bridge Wharf, London, N.
1910		INGLIS, GEORGE ALEXANDER, B.Sc., 64 Warroch Street, Glasgow.

1910		JACK, HENRY JOSEPH,
		    The Aluminium Corporation, Limited, 52 Coleman
		        Street, E.C.

1908–9		JACOB, ARTHUR,
		    The British Aluminium Company, Limited, 109
		        Queen Victoria Street, E.C.

1908–9		JACOB, HENRY, Henry Jacob & Company, 9 Water Lane, E.C.
1908–9		JACOBS, HARRY, Exchange Buildings, New Street, Birmingham.
1908–9		JAGO, WILLIAM HENRY, 59 Vancouver Road, Forest Hill, S.E.
1912		JAMES, GARNET WILLIAMS, M.A. (Oxon.), J. Stone & Company, Limited, Deptford, S.E.

1914		JAMESON, CHARLES GODFREY,
		    The British Aluminium Company, Limited,
		        Kinlochleven, Argyllshire.

Elected Member.		
1911		JARRY, E. V., R. Buckland & Son, 10/11 Hop Gardens, St. Martin's Lane, W.C.
1912		JENNISON, HERBERT CHARNOCK, P.O. Box 348, Ansonia, Conn., U.S.A.
1908–9		JOHNSON, ARTHUR LAURENCE, M.A., Woodleigh, Altrincham.
1908–9		JOHNSON, BERNARD ANGAS, c/o National Provincial Bank, Finchley Road, Hampstead, N.W.
1908–9		JOHNSON, ERNEST, M.A., Richard Johnson & Nephew, Limited, Bradford Iron Works, Manchester.
1908–9	†	JOHNSON, FREDERICK, M.Sc., Metallurgical Department, Municipal Technical School, Suffolk Street, Birmingham.
1908–9		JOHNSON, HAROLD MARSLAND, Bradford Iron Works, Manchester.
1908–9		JOHNSON, WILLIAM MORTON, M.A., Richard Johnson, Clapham & Morris, Limited, 24 Lever Street, Manchester.
1908–9		JUDE, ALEXANDER ARCHIE, Belliss and Morcom, Limited, Birmingham.
1908–9		KAMPS, HANS, Directeur de la Fabrique Nationale de Tubes sans Soudre, Merxem-lez-Anvers, Belgium.
1908–9		KAYE, HARRY, H. B. Barnard & Sons, 148½ Fenchurch Street, E.C.
1908–9		KEELING, A. D., Warstone Metal Works, Hall Street, Birmingham.
1908–9		KEIFFENHEIM, ERWIN CHARLES, The Metallurgical Company, A. Keiffenheim and Sons, Milburn House, Newcastle-on-Tyne.
1908–9		KEMP, JOHN FRANK, A. Kemp & Son, Tenby Street North, Birmingham.
1908–9		KENDREW, THOMAS, Broughton Copper Company, Limited, Manchester.
1910		KIDSTON, WILLIAM HAMILTON, 81 Great Clyde Street, Glasgow.
1908–9		KING, ERNEST GERALD, Editor, *The Metal Industry*, 33 Bedford Street, Strand, W.C.
1908–9		KIRKPATRICK, VINCENT, Closeburn, Hartopp Road, Four Oaks, Sutton Coldfield, Birmingham.
1908–9	†	KLEIN, CARL ADOLPHE, 4 Brimsdown Avenue, Enfield Highway, Middlesex.

Elected Member.		

1908–9		Lacy, William Yaveir,
		    Oak Mount, Westbourne Road, Edgbaston,
		      Birmingham.

1908–9		Laing, Andrew, 15 Osborne Road, Newcastle-on-Tyne.
1912		Lambert, Arthur Reginald, Mitsui & Company, Limited, 33 Lime Street, E.C.
1913		Lambert, Wesley, A. K. C., " Whitefriars," 41 Bromley Road, Catford, S.E.

1908–9		Lancaster, Harry Charles,
		    Locke, Lancaster and W. W. and R. Johnson and
		      Sons, Limited, 14 Fenchurch Street, E.C.

1908–9		Landsberg, Heinrich,
		    Heddernheimer Kupferwerk und Süddeutsche
		      Kabelwerke, Aktiengesellschaft, Frankfurt-am-
		      Main, Germany.

1908–9		Lang, Charles Russell,
		    G. & J. Weir, Limited, Holm Foundry, Cathcart,
		      Glasgow.

1908–9		Langdon, Palmer H., Editor, *The Metal Industry*, 99 John Street, New York City, U.S.A.
1908–9		Langenbach, Oscar, 17 Bolton Gardens, S.W.
1908–9		Lantsberry, Frederick C. A. H., M.Sc., 63 Walford Road, Sparkbrook, Birmingham.

1908–9	†	Law, Edward Fulton, A.R.S.M.,
		    Sir W. G. Armstrong, Whitworth & Company,
		      Limited, Ashton Road, Openshaw, Man-
		      chester.

1911		Lazarus, William, 193 Regent Street, W.

1911		Ledoux, Albert Reid, A.M., M.S., Ph.D.,
		    Ledoux & Company, 99 John Street, New York
		      City, N.Y., U.S.A.

1908–9		Lees, Charles, Loanda, Wickwar, Gloucester.

1908–9		Leigh, Cecil,
		    Birmingham Metal and Munitions Company,
		      Limited, Birmingham.

1908–9		Leslie, Robert,
		    P. & O. Steam Navigation Company, 122
		      Leadenhall Street, E.C.

1908–9		Lessner, Charles Blüthner, The San Finx Tin Mines, Limited, Carril, Spain.

1908–9		Lester, Walter,
		    The Phosphor Bronze Company, Limited, 87
		      Sumner Street, S.E.

Elected Member.		
1911		LETCHER, WILLIAM WHITBURN, 84 Queen Elizabeth's Walk, Lordship Park, N.
1910		LEVI, CLIVE JOSEPH, B.Sc., 143 Newhall Street, Birmingham.
1912		LITTLE, ARTHUR DEHON, Arthur D. Little, Inc., 93 Broad Street, Boston, Mass., U.S.A.
1911		LIVERSIDGE, Engineer-Commander EDWARD WILLIAM, R.N., H.M. Torpedo Depôt, Chatham Dockyard.
1908–9		LONGMUIR, PERCY, D.Met., Ravenscrag, Wortley, near Sheffield.
1908–9		LORD, FITZHERBERT ALBERT BUGBY, 49 Queen Victoria Street, E.C.
1910	†	LOUIS, Professor HENRY, M.A., D.Sc., A.R.S.M., 4 Osborne Terrace, Newcastle-on-Tyne.
1910		LOW, ARCHIBALD NICOL, Partick Brass Foundry Company, Merkland Works, Partick, Glasgow.
1908–9		McCONWELL, ARTHUR, 60 Drury Buildings, Water Street, Liverpool.
1910		MACFEE, ROBERT, 15 Alexandra Grove, Chorlton-on-Medlock, Manchester.
1912		MacINTOSH, JAMES RAE, B.Sc. (Glas.), Siemens Brothers Dynamo Works, Limited, Central House, Birmingham.
1908–9		McKECHNIE, ALEXANDER, McKechnie Brothers, Rotton Park Street, Birmingham.
1910		McKECHNIE, JAMES, Vickers, Limited, Barrow-in-Furness.
1908–9		MACKENZIE, WILLIAM, McKechnie Brothers, 90 Pilgrim Street, Newcastle-on-Tyne.
1908–9		McLAURIN, Engineer-Commander JOHN, R.N., The Laurels, Branksome Wood Road, Fleet, Hampshire.
1908–9	†	McWILLIAM, Professor ANDREW, A.R.S.M., D.Met. (Shef.), Kalimati, B. N. Railway, India.
1913		MAIN, Engineer-Commander REUBEN, R.N., 86 Cavendish Drive, Rock Ferry, Cheshire.
1912		MALBY, SETH GRANT, Aluminium Company of America, 99 John Street, New York City, U.S.A.
1911		MALLISONT, GEORGE, 5 South Cliffe Avenue, Eastbourne.

Elected Member.		

1914		MANNELL, JOHN,
		    G. Thompson & Company, Limited, Aberdeen
		      White-Star Line, Billiter Square, E.C.

1908–9		MAPPLEBECK, EDWARD, Liverpool Street, Birmingham.

1908–9		MAPPLEBECK, EDWARD PERCY WILKES,
		    J. Wilkes, Sons & Mapplebeck, Limited, Liverpool
		      Street, Birmingham.

1912		MARSHALL, Engineer-Commander FREDERICK WILLIAM,
		    R.N.
		    H.M.S. "Monarch," 2nd Battle Squadron, Home
		      Fleet.

1910		MASON, FRANK, Wayland House, 70 Wayland Road, Sheffield.
1910		MAW, WILLIAM HENRY, LL.D., 18 Addison Road, Kensington, W.
1908–9		MAY, WILLIAM WALKER, Woodbourne, Minard Avenue, Partickhill, Glasgow.
1913		MAYO, CHARLES ROBERT, 155 Dashwood House, New Broad Street, E.C.
1908–9		MENZIES, JOHN, Merton Abbey, S.W.
1908–9		MERCER, JAMES BURY, Hollycroft, Deepthwaite, Milnthorpe, Westmorland.
1908–9		MERRETT, WILLIAM HENRY, A.R.S.M., Hatherley, Grosvenor Road, Wallington, Surrey.
1908–9		MEYJES, ANTHONY CORNELIUS, Editor, *The Ironmonger*, 42 Cannon Street, E.C.
1910		MEYRICK, LEWIS JENKIN, 137 City Road, Birmingham.

1911		MICHIE, ARTHUR C., D.Sc.,
		    The Wallsend Laboratories, Neptune Road,
		      Wallsend-on-Tyne.

1908–9		MILLER, JOHN, 365 Potomoe Avenue, Buffalo, N.Y., U.S.A.
1908–9		MILLINGTON, ERNEST, Manor Road, Borrowash, Derby.

1908–9		MILLS, EDWARD,
		    Williams, Foster & Company, and Pascoe,
		      Grenfell & Sons, Limited, Morfa Copper
		      Works, Swansea.

1912		MILLS, HARRY,
		    Grice, Grice & Son, Limited, Nile Street,
		      Birmingham.

1908–9	†	MILLS, JOHN HODGSON,
		    Atlas Aluminium Works, Grove Street, Birming-
		      ham.

Elected Member.		
1908–9		MILLS, WILLIAM, "Danesbury," Alderbrook Road, Solihull, Warwickshire.
1908–9	†	*MILTON, JAMES TAYLER (Vice-President),* *Lloyd's Register of British and Foreign Shipping, 71 Fenchurch Street, E.C.*
1908–9		MITTON, THOMAS E., Hunt & Mitton, Crown Brass Works, Oozells Street North, Birmingham.
1908–9		MORCOM, EDGAR LLEWELLYN, M.A. (Cantab.), Trencrom, Woodbourne Road, Edgbaston, Birmingham.
1910		MOREHEAD, CHARLES, 72 Highbury, West Jesmond, Newcastle-on-Tyne.
1913		MORISON, Engineer-Commander RICHARD BARNS, R.N., The Admiralty, Whitehall, Westminster, S.W.
1908–9		MORISON, WILLIAM, 172 Lancefield Street, Glasgow.
1908–9		*MORRISON, WILLIAM MURRAY,* *The British Aluminium Company, Limited, 109 Queen Victoria Street, E.C.*
1914		MORTIMER, Eng.-Com. JOHN ERNEST, R.N. (Rtd.), 34 Victoria Street, Westminster, S.W.
1908–9		MOUNT, EDWARD, Oaklands, Aughton, near Ormskirk, Lancashire.
1913		MUIRHEAD, WILLIAM, Holmfield, Kirkintilloch, Renfrewshire.
1909		MÜNKER, EMIL, III Sechskrügelgasse 8, Vienna, Austria.
1908–9	†	*MUNTZ, Sir GERARD ALBERT, Bart. (Past-President),* *Muntz's Metal Company, Limited, French Walls, near Birmingham.*
1910	†	MURRAY, MYLES THORNTON, M.Sc., South African School of Mines, Johannesburg, Transvaal, South Africa.
1908–9		MURRAY, WILLIAM, Jun., John Mills & Sons, Walker-Gate Brass Works, Newcastle-on-Tyne.
1912		NARRACOTT, RONALD WILLIAM, D.Sc., The James Bridge Copper Works, Walsall.
1912		NEAD, JOHN HUNTER, B.S., 17 Paul Street, Watertown, Mass., U.S.A.
1908–9		NESBIT, DAVID MEIN, Northumbria, Knighton Drive, Leicester.
1908–9		NIGGEMANN, BERNHARD JOSEPH, 26 Chapel Street, Liverpool.

Elected Member.		

1908–9		NISBETT, GEORGE HIND,
		    British Insulated and Helsby Cables, Limited,
		        Prescot, Lancashire.

1908–9		NORMAN, JOHN THOMAS,
		    The City Central Laboratory, 23 Leadenhall Street,
		        E.C.

1910		OAKDEN, Professor WILLIAM EDWARD, 2 Gladhow Terrace, South Kensington, S.W.
1908–9		OGG, Major GEORGE SIM, R.A., *Address missing.*
1912		OLSSON, MARTIN CAMPBELL, 6 St. Helen's Place, E.C.
1910		ONYON, Engineer-Captain WILLIAM, M.V.O., R.N., W. Beardmore & Co., Dalmuir, N.B.

1908–9	†	*ORAM, Engineer Vice-Admiral Sir HENRY JOHN, K.C.B.,*
		    F.R.S. (President),
		        The Admiralty, Whitehall, Westminster, S.W.

1908–9		ORDE, EDWIN LANCELOT,
		    Sir W. G. Armstrong, Whitworth & Company,
		        Limited, Walker Shipyard, Newcastle-on-
		        Tyne.

1908–9		OWEN, HALSALL, Burfield, Appleton, near Warrington.
1912		PALMER, ARTHUR CECIL HUNTER, Queensland Government Offices, 410 Strand, W.C.
1908–9		PARKER, WILLIAM BAYLEY, 1 Murray Road, Rugby.

1908–9		*PARSONS, The Hon. Sir CHARLES ALGERNON, K.C.B.,*
		    LL.D., D.Sc., M.A., D.Eng., F.R.S.,
		        Holeyn Hall, Wylam-on-Tyne.

1911		PARSONS, The Hon. GEOFFRY LAURENCE, M.A. (Oxon.),
		    C. A. Parsons & Company, Heaton Works,
		        Newcastle-on-Tyne.

1908–9		PATCHETT, Colonel JAMES,
		    The Shropshire Iron Company, Limited, Hadley,
		        near Wellington, Shropshire.

1910		PATERSON, DAVID, Vickers Street, Miles Platting, Manchester.

1908–9		PATERSON, JOHN,
		    Park & Paterson, Limited, 22 Backcauseway Street,
		        Parkhead, Glasgow.

1908–9		PATERSON, WILLIAM,
		    Park & Paterson, Limited, 22 Backcauseway Street,
		        Parkhead, Glasgow.

Elected Member.		
1908–9		PAUL, MATTHEW, Levenford Works, Dumbarton.
1908–9		PEARCE, GILBERT BENNETT, "The Beeches," Hayle, Cornwall.
1908–9		PEARCE, RICHARD, Ph.D. (Columb.), 6 Beach Lawn, Waterloo, Liverpool.
1908–9		PEARSON, GEORGE CHARLES, 129 Victoria Road, Old Charlton, S.E.
1908–9		PETAVEL, Professor JOSEPH ERNEST, D.Sc. (Man.), F.R.S., The University, Manchester.
1913		PHELPS, JOHN, M.A. (Oxon.), Newcroft, Egmont Road, Sutton, Surrey.
1908–9	†	*PHILIP, ARNOLD, B.Sc., A.R.S.M.,* *Admiralty Chemist's Department, H.M. Dockyard,* *Portsmouth.*
1908–9		PHILLIPS, HENRY HARCOURT, Lynwood, Turton, Lancashire.
1912		PLAYER, WILLIAM, 54 Calthorpe Road, Edgbaston, Birmingham.
1913		POLLARD, WILLIAM BRANCH, B.A., Beit-el-Barrache, Bulak Dakrur, Egypt.
1908–9		POPPLETON, GEORGE GRAHAM, C.A., C.C. (Honorary Auditor), 26 Corporation Street, Birmingham.
1908–9		POTTIE, GEORGE, 42 Mansfield Road, Ilford, Essex.
1911		PREECE, ARTHUR HENRY, Preece, Cardew & Snell, 8 Queen Anne's Gate, Westminster, S.W.
1908–9		PRESTON, PANIZZI, Landford Manor, Salisbury, Wiltshire.
1912		PRICE, WILLIAM B., Ph.B., Scovill Manufacturing Company, Waterbury, Conn., U.S.A.
1908–9	†	PRIMROSE, HARRY STEWART, Usines Carels Frères, Ghent, Belgium.
1908–9	†	PRIMROSE, JOHN STEWART GLEN, Consolidated Diesel Engine Manufacturers, Limi- ted, Ipswich.
1914		QUIN, LAWRENCE HOWARD, 3 East India Avenue, E.C.
1908–9		QUIRK, GEORGE HENRY, 33 Bishopsgate, E.C.
1908–9		QUIRK, JOHN STEBLE, Quirk, Barton & Burns, St. Helens, Lancashire.

Elected Member.		
1908–9		RADLEY, WILLIAM ALBERT, 5 Lyddon Terrace, Leeds.
1914		RANDALL, Engineer-Lieutenant CHARLES RUSSELL JEKYL, R.N., 2 Furness Park Road, Barrow-in-Furness.
1911		RAO, SESHAGIRI RAGHAVENDRA, B.A., B.Sc., Superintendent of Industries, Camp Kunigal, Mysore Province, India.
1913		RASQUINET, ALBERT, 84 Rue de Froidmont, Liége, Belgium.
1911		RAVEN, VINCENT LITCHFIELD, North-Eastern Railway, Darlington.
1913		RAWORTH, BENJAMIN ALFRED, Wh.Sc., *Engineering*, 35 and 36 Bedford St., Strand, W.C.
1913	†	READ, Professor ARTHUR AVERY, M.Met. (Shef.), University College, Cardiff.
1908–9		REDDING, FREDERICK CHAPMAN, Gun and Shell Factory, Cossipore, E.B.S. Railway, near Calcutta, India.
1910		REDWOOD, Sir BOVERTON, Bart., D.Sc., The Cloisters, 18 Avenue Road, Regent's Park, N.W.
1908–9		REED, JOSEPH WILLIAM, Mayfield, Jarrow-on-Tyne.
1908–9		REID, ANDREW THOMSON, Hyde Park Locomotive Works, Glasgow.
1908–9		REID, EDWIN SAFFORD, National Conduit and Cable Company, Limited, Oxford Court, Cannon Street, E.C.
1912		REJTÖ, Professor A., Müegyetem, Budapest, Hungary.
1913		RENAUD, VICTOR, 22 Quai des Moines, Ghent, Belgium.
1908–9	†	RHEAD, EZRA LOBB, M.Sc.Tech., Municipal School of Technology, Manchester.
1908–9		RICHARDS, Engineer-Commander JOHN ARTHUR, R.N., 47 Ridgmount Gardens, W.C.
1913		RIDER, JOSEPH JACKSON, " Roxton," Chester Road, Erdington, Birmingham.
1908–9		RIDGE, HARRY MACKENZIE, H. M. Ridge & Company, 62 London Wall, E.C.
1908–9		RIGBY, ROBERT, New John Street Metal Works, Birmingham.
1914		RIX, HARRY, 333 Stretford Road, Hulme, Manchester.
1914		ROBERTON, CHARLES GEORGE, 12 Cavendish Park, Barrow-in-Furness.

Elected Member.		
1908–9	†	ROBERTSON, WALTER HENRY ANTONIO, Robertson & Company, Limited, Engineers, Lynton Works, Bedford.
1911		ROBINSON, JOSEPH HENRY, Globe Road, E.
1908–9		ROBSON, OSWALD HENRY, 273 New Cross Road, S.E.
1908–9		RODGERS, JOHN, Joseph Rodgers & Sons, Limited, 6 Norfolk Street, Sheffield.
1908–9		ROGERS, HENRY, "Gartly," 75 Blenheim Road, Moseley, Birmingham.
1910		RONALD, HENRY, Brybton House, Warwick Road, Olton, Warwickshire.
1912		ROSAMBERT, CHARLES, Metallwerk, Manfred Weiss, Ctépel, near Budapest, Hungary.
1912	†	ROSE, THOMAS KIRKE, D.Sc. (Lond.), A.R.S.M., Royal Mint, E.
1908–9	†	*ROSENHAIN, WALTER,* D.Sc. *(Melb.),* F.R.S., *The National Physical Laboratory, Teddington, Middlesex.*
1909		ROSENTHAL, JAMES HERMANN, Babcock & Wilcox, Ltd., Oriel House, Farringdon Street, E.C.
1913		ROSS, ARCHIBALD JOHN CAMPBELL, R. & W. Hawthorn, Leslie & Company, Limited, Newcastle-on-Tyne.
1908–9		ROWLEY, ERNEST WHITWORTH, Chemical Laboratory, North-Eastern Railway, Darlington.
1908–9		RUCK, EDWIN, 19 Bryn Road, Swansea.
1908–9		RUCK-KEENE, HARRY ARTHUR, Lloyd's Register of British and Foreign Shipping, 71 Fenchurch Street, E.C.
1908–9		RUSH, Engineer-Commander HENRY CHARLES, R.N., Bryn Elvet, Halesworth, Suffolk.
1908–9		RUSSELL, CHARLES ARTHUR, C. Holdin & Company, Limited, 17 Exchange Buildings, Birmingham.
1911		RUSSELL, STUART ARTHUR, India-rubber, Gutta-percha, and Telegraph Works Company, Limited, Silvertown, E.
1908–9		RUTHENBURG, MARCUS, 1 Kingsway, W.C.

Elected Member.		
1908–9		RUTHERFORD, WILLIAM PATERSON, The Tharsis Sulphur and Copper Company, 136 West George Street, Glasgow.
1908–9		RYDER, TOM, Thomas Ryder & Son, Turner Bridge Works, Tonge, Bolton.
1911		SAKLATWALLA, B. D., B.Sc., Dr.Ing., American Vanadium Co., Bridgeville, Pa., U.S.A.
1908–9		SALES, HARRY, 15 Musgrove Road, New Cross, S.E.
1914		SANDERS, ALFRED, 5 and 6 Warstone Lane, Birmingham.
1913		SAPOSHNIKOW, Professor ALEXIS, Zabalkansky pr. 9, St. Petersburg, Russia.
1912		SAUVEUR, Professor ALBERT, S.B., 20 Elmwood Avenue, Cambridge, Mass., U.S.A.
1912		SCHLEICHER, ALADAR PAUL, Ph.D., Mérleg-utcza, 11 I., Budapest, V., Hungary.
1908–9		SCHLUND, LÉON, M.Sc., 32 Clerkenwell Road, E.C.
1909		SCOTT, AUGUSTINE ALBAN HAMILTON, 13 Old Square, Lincoln's Inn, W.C.
1908–9		SCOTT, CHARLES, Scott & Hodgson, Ltd., Guide Bridge Iron Works, near Manchester.
1908–9		*SEATON, ALBERT EDWARD,* *32 Victoria Street, S.W.*
1908–9	†	SELIGMAN, RICHARD, Ph.Nat.D., Point Pleasant, Putney Bridge Road, Wandsworth, S.W.
1908–9		SELIGMANN, HARDY, 38 Lime Street, E.C.
1912		SHARPLES, JAMES, 846 Ashton Old Road, Higher Openshaw, Manchester.
1909		SHEPPARD, ROBIN MYLREA, French Walls, Birmingham.
1908–9	†	SIEMENS, ALEXANDER, Siemens Brothers & Company, Limited, Caxton House, Westminster, S.W.
1908–9		SILVESTER, HARRY, B.Sc., 36 Paradise Street, Birmingham.
1908–9		SIMKINS, ALFRED GEORGE, Walkers, Parker & Company, Limited, 63 Belvedere Road, Lambeth, S.E.

Elected Member.		
1908–9		SINCLAIR, ALEXANDER, 6 Richmond Villas, Swansea.
1912		SITWELL, Captain NORMAN SISSON HURT, R.A., Ammunition Factory, Dum Dum, Bengal, India.
1910		SJÖGREN, ANDREAS SAMUEL, Svenska Metällverken, Gothenburg, Sweden.

1912		SJÖGREN, JUSTUS FREDRIK,
		    S. A. Edwards & Company, Limited, 30 Easy Row,
		        Birmingham.

1913		SKELTON, HERBERT ASHLIN,
		    The British Aluminium Company, Limited, Foyers,
		        Inverness-shire.

1913		SKILLMAN, VERNE, Lumen Bearing Company, Buffalo, N.Y., U.S.A.
1908–9	†	SMITH, ERNEST ALFRED, A.R.S.M., Assay Office, Leopold Street, Sheffield.
1908–9		SMITH, FREDERIC, Anaconda Works, Salford, Manchester.
1908–9		SMITH, HUGH DUNFORD, 7 and 9 The Side, Newcastle-on-Tyne.
1908–9		SMITH, HERBERT MELVILLE, Hill Top, Abbey Wood, Kent.
1908–9		SMITH, HERBERT PROCTER, Hawarden Bridge Steel Works, Shotton, Chester.
1908–9		SMITH, PHILIP WARTON, 5 Philpot Lane, E.C.
1910		SMITH, SYDNEY WILLIAM, B.Sc., A.R.S.M., Royal Mint, E.
1912		*SMITH, Sir WILLIAM EDWARD, C.B.,* *10 Hillbury Road, Balham, S.W.*

1914		SPEIER, LEOPOLD,
		    Altheimer Speier & Company, Frankfurt-am-Main,
		        Germany.

1908–9		SPITTLE, ARTHUR, 30 Regent Street, Smethwick, Birmingham.
1914		SPYER, ARTHUR, Oriel House, Farringdon Street, E.C.

1909		STANLEY, Professor GEORGE HARDY, A.R.S.M.,
		    South African School of Mines, P.O. Box 1176,
		        Johannesburg, South Africa.

1908–9		STANLEY, WILLIAM NEEMS,
		    12 Spencer Road, Cottenham Park, Wimbledon,
		        Surrey.

1908–9		STANSFIELD, Professor ALFRED A., D.Sc. (Lond.), A.R.S.M.,
		    Chemistry Building, McGill University, Montreal,
		        Canada.

Elected Member.		
1908–9	†	STEAD, JOHN EDWARD, D.Sc., D.Met., F.R.S., 11 Queen's Terrace, Middlesbrough.
1911		STENHOUSE, THOMAS, B.Sc. (Lond.), A.R.S.M., Admiralty Chemist's Department, H.M. Dockyard, Portsmouth.
1908–9		STEPHEN, ALEXANDER EDWARD, Linthouse, Govan, Glasgow.
1908–9		STEVEN, CARL, Carlswerk, Mülheim-am-Rhein, Germany.
1908–9		STEVEN, JAMES, Steven & Struthers, Eastvale Place, Kelvinhaugh, Glasgow.
1910		STEVENS, VICTOR G., 75 Livingstone Road, King's Heath, Birmingham.
1910		STEVENSON, ROBERT, 72/80 Brown Street, Glasgow.
1913		STEWARDSON, GEORGE, 80A Taranaki Street, Wellington, New Zealand.
1908–9		STOCKHAUSEN, FRIEDRICH, Ph.D., Weissfrauen Strasse 7/9, Frankfurt-am-Main, Germany.
1911		STONEY, GEORGE GERALD, F.R.S., "Oakley," Heaton Road North, Newcastle-on-Tyne.
1908–9		STOREY, WILLIAM EDWARD, Lowood, Torrington Park, North Finchley, N.
1908–9		STRANGE, HENRY, 8 Boldmere Road, Erdington, Birmingham.
1910		STUTZ, R., Thermit, Limited, 27 Martin's Lane, Cannon Street, E.C.
1908–9		SULMAN, HENRY LIVINGSTONE, 44 London Wall, E.C.
1908–9		*SUMNER, LEONARD*, M.Sc., *The Broughton Copper Works, Manchester.*
1908–9		SUTHERLAND, JOHN, The Bauxite Refining Company, Hebburn-on-Tyne.
1910		SWIFT, JAMES BEAUMONT, 77 Upper Tulse Hill, S.W.
1911		SYMONDS, HARRY LAMBERT, "Sunnyside," Woodland Avenue, Hornchurch, Romford.
1908–9		TAWARA, Professor KUNÜCHI, 5 Kamifujimayechō, Komagome, Hongō, Tokyo, Japan.

Elected Member		
1908–9		TAYLOR, CHARLES, Lathe and Tool Works, Bartholomew Street, Birmingham.
1913		TAYLOR, Engineer-Captain CHARLES GERALD, R.N., Royal Naval College, Keyham, Devonport.
1911		TAYLOR, CHARLES WARDROPE, North-Eastern Foundry and Engineering Works, South Shields.
1908–9		TAYLOR, J. S., The Corinthians, Acock's Green, Birmingham.
1911		TAYLOR, WILLIAM IVAN, Kynock, Limited, Umbogintwini, Durban, S. Africa.
1910		TEAROE, JAMES, The Queensland Government Offices, 409 Strand, W.C.
1908–9		TEED, Engineer-Commander HENRY RICHARD, R.N., 54 Riverdale Road, Sheffield.
1908–9		TERTZWEIL, LÉON, Clouterie des Flandres, Gentbrugge, Belgium.
1911		THOMAS, FRANK MORETON, Stores Superintendent, Port of London Authority, 106 Fenchurch Street, E.C.
1908–9		THOMAS, HUBERT SPENCE, Melingriffith Works, near Cardiff, South Wales.
1912		THOMPSON, JOHN FAIRFIELD, B.Sc., Ph.D. (Columb.), The International Nickel Company, Orford Works, Bayonne, New Jersey, U.S.A.
1910		THOMPSON, ROBERT, 155 Fenchurch Street, E.C.
1908–9		THORNE, EMMANUEL ISAAC, 13 Cantwell Road, Plumstead, Kent.
1908–9		TIDSALL, EUGENE, 49 Willow Road, Bournville, Birmingham.
1912		TIEMANN, HUGH PHILIP, B.S., A.M. (Columb.), Carnegie Building, Pittsburg, Pa., U.S.A.
1908–9		TITLEY, ARTHUR, Titley & Wall, Curzon Chambers, Paradise Street, Birmingham.
1908–9		TOMLINSON, FREDERICK, Broughton Copper Company, Limited, Manchester.
1912	†	TUCKER, ALEXANDER EDWIN, 55 Station Street, Birmingham.
1911		TUCKER, PERCY ALEXANDER, "Cedar Court," Aldridge, Staffordshire.
1908–9		TURNBULL, NICHOLAS KING, 3 York Street, Manchester.

Elected Member.		
1911		TURNER, ALFRED, 70 Cavendish Road, Edgbaston, Birmingham.
1913		TURNER, HAROLD, 73–79 Eyre Street, Sheffield.
1908–9	†	TURNER, *Professor* THOMAS, *M.Sc.* (*Birm.*), *A.R.S.M.* (*Vice-President and Honorary Treasurer*), *The University, Edgbaston, Birmingham.*
1913		TYSCHNOFF, WSEWOLOD, Motowilicha, Perm Gun Works, Perm, Russia.
1911		VANCE, ROBERT, Lloyd's Register of British and Foreign Shipping, Caixa 636, Rio de Janeiro, Brazil, South America.
1914		VARLEY, JOHN WILLIAM, Honorville, Finnemore Road, Ideal Village, Little Bromwich, Birmingham.
1908–9		VAUGHAN, WILLIAM ISAIAH, Cogan House, Sully Road, near Penarth, Glamorganshire.
1908–9		VIVIAN, HUGH, Vivian & Sons, Hafod Copper Works, Swansea.
1908–9		VIVIAN, The Hon. ODO RICHARD, *M.V.O.*, Vivian & Sons, Hafod Copper Works, Swansea.
1912		WAINWRIGHT, THOMAS GEORGE, Fern Lea, Stocks Lane, Stalybridge, Manchester.
1911		WALES, THOMAS COULTHARD, T. W. Ward, Limited, Albion Works, Sheffield.
1910		WALKER, HERBERT CARR, Tyrie, Greenhead Road, West Park, Headingley, Leeds.
1911		WALKER, JAMES WILLIAM, Churnet View, Oakamoor, Stoke-on-Trent.
1908–9		WALMSLEY, ROBERT MULLINEUX, *D.Sc.*, *F.R.S.E.* Principal, Northampton Polytechnic Institute, E.C.
1914		WALTERS, WILLIAM LLEWELLYN, 5 Knole Avenue, Swansea.
1913		WARBURTON, FREDERICK WILLIAM, Duram Works, Hanwell, W.
1908–9		WATSON, FREDERICK MACKMAN, Cranworth House, Rotherham.
1908–9		WATSON, GEORGE COGHLAN, St. George's Wharf, Deptford, S.E.
1908–9		WATSON, WILLIAM EDWARD, Atlas Metal and Alloys Company, 52 Queen Victoria Street, E.C.

Elected Member.	
1914	WATTS, Sir PHILIP, K.C.B., F.R.S., 10 Chelsea Embankment, S.W.
1908–9	WEBB, ARTHUR JAMES, M.A., B.Sc., Johnson, Matthey & Company, Limited, 78 Hatton Garden, E.C.
1914	WEBB, HERBERT ARTHUR, 18 Sheredan Road, Highams Park, Chingford, N.E.
1908–9	WEBSTER, WILLIAM REUBEN, Bridgeport Brass Co., Bridgeport, Conn., U.S.A.
1908–9	WEEKS, HENRY BRIDGES, Vickers, Limited, Barrow-in-Furness.
1908–9	WEIR, WILLIAM, Holm Foundry, Cathcart, Glasgow.
1912	WEISS, EUGEN VON, Andrassy-ut 116, Budapest, Hungary.
1910	WESTWOOD, ARTHUR, Assay Office, Birmingham.
1908–9	WHEELER, RICHARD VERNON, D.Sc., Home Office Experimental Station, Eskmeals, Cumberland.
1911	WHIPPLE, ROBERT STEWART, Cambridge Scientific Instrument Company, Limited, Cambridge.
1911	WHITE, Colonel RICHARD SAXTON, V.D., Shirley, Jesmond, Newcastle-on-Tyne.
1911	WHITNEY, WILLIS R., B.S., Ph.D. (Leip.), Research Laboratory, General Electric Co., Schenectady, N.Y., U.S.A.
1910	WHITWORTH, LESLIE, 2 Palace Gardens, Enfield, N.
1908–9	WIDDOWSON, JOHN HENRY, 25 Withington Road, Whalley Range, Manchester.
1908–9	WIGGIN, ALFRED HAROLD, B.A., Bordesley Hall, Alvechurch, Worcestershire.
1908–9	WIGGIN, CHARLES RICHARD HENRY, B.A., The Forehill House, near King's Norton, Worcestershire.
1908–9	WIGGIN, Sir HENRY ARTHUR, Bart., Walton Hall, Eccleshall, Staffordshire.
1913	WILKES, JOSEPH, 75 Hillaries Road, Gravelly Hill, Birmingham.
1908–9	WILKINS, HARRY, 99 Rustlings Road, Sheffield.
1908–9	WILLIAMS, HAROLD WILFRED, Grand Hotel, Birmingham.
1914	WILLIAMS, HARRIS GREGORY, "Boscombe," Elmfield Road, Gosforth, Newcastle-on-Tyne.

Elected Member.		
1908–9	†	WILLOTT, FREDERIC JOHN, The Priestman Collieries, Ltd., Milburn House, Newcastle-on-Tyne.
1910		WILSON, ANTHONY, Braithwaite, Keswick.
1908–9		*WILSON, CECIL HENRY,* *Sheffield Smelting Company, Limited, Sheffield.*
1908–9		WILSON, JAMES HOWARD, Dorridge House, Dorridge, Warwickshire.
1908–9		WILSON, JOHN HOWARD, 15 Thornsett Road, Sharrow, Sheffield.
1908–9		WILSON, OSBORNE ERNEST, "Meadow Bank," Kingston Road, Didsbury, Manchester.
1910		WISNOM, Engineer-Commander WILLIAM McKEE, R.N., Denny & Co., Engine Works, Dumbarton, N.B.
1908–9		WOOD, RICHARD SIBBERING-, Coventry Ordnance Works, Limited, Coventry.
1911		WOOD, Engineer-Commander WILLIAM HENRY, R.N., John Brown & Company, Limited, Clydebank, Scotland.
1910		WOODHOUSE, HENRY, Radley House, 80 High Street, Cheshunt, Herts.
1914		WOOLLVEN, ROLFE ARMSTRONG, "Fairview," Cedar Road, Sutton, Surrey.
1910		WOORE, HAROLD LINTON LEA, "West Bank," Epping, Essex.
1912		WRIGHT, CHARLES WILLIAM, 2 Evelyn Street, Deptford, S.E.
1908–9		WRIGHT, REGINALD, Nasmyth, Wilson & Co., Bridgewater Foundry, Patricroft, near Manchester.
1913		WÜST, Geh. Reg. Rat. Prof. Dr.Ing. FRITZ, Ludwigsallee 47, Aachen, Germany.
1914		YARDLEY, WILLIAM HENRY, Princeps & Company, Matilda Street, Sheffield.
1908–9		YARROW, ALFRED FERNANDEZ, Campsie Dene, Blanefield, Stirlingshire.
1911		YOUNG, HORACE JOHN, North-Eastern Marine Engineering Company, Limited, Northumberland Engine Works, Wallsend-on-Tyne.
1911		ZAPF, GEORGE, Felton & Guilleaume Carlswerk, A. G., Mülheim-am-Rhein, Germany.

STUDENT MEMBERS

Elected Members.		
1910		ALMOND, GEORGE, Meek, Holt County, Nebraska, U.S.A.
1908–9	†	BRÜHL, PAUL THEODOR, M.Sc., Société Française des Mines de Cuivre, Collahuasi La Grande, Chili, South America.
1910		CARTLAND, JOHN, M.Sc., Solihull, Warwickshire.
1911		CROSIER, EDWARD THEODORE, 51 Clarence Road, Teddington, Middlesex.
1910		DAWSON, STANLEY ERNEST, 21 Hayburn Crescent, Partick, Glasgow.
1913		GIBSON, HESELTINE, 9 Barnsley Road, Edgbaston, Birmingham.
1913		GRESTY, COLIN, Northumberland Engine Works, Wallsend-on-Tyne.
1913		HEATH, WILLIAM STANLEY, Heather Rocks, Stockton Brook, Stoke-on-Trent.
1910		HUBBARD, NORMAN FREDERICK SEPTIMUS, B.Sc., 23 Plymouth Avenue, Manchester.
1910		HUNTER, SUMMERS, Jun., 1 Manor Terrace, Tynemouth, Northumberland.
1911		JENKINS, IVOR OWEN, "Gwynfa," Penywern, Neath, South Wales.
1912		JOHNSON, ALBERT WILLIAM, 31 Angus Street, New Cross, S.E.
1913		NEVILL, RICHARD WALTER, B.Sc., "Clovelly," Earlsdon Avenue, Coventry.
1910		PATERSON, WILLIAM, Jun., Braemar, Parkhead, Glasgow.
1911		POWELL, HARRY, Hawthorn, Leslie & Co., Ltd., St. Peter's Works, Newcastle-on-Tyne.
1908–9		SHARP, ROBERT S., "St. Lucia," Nithsdale Road, Dumbreck, Glasgow.
1910	†	TABOR, HOWARD JAMES, 17 Sebert Road, Forest Gate, E.
1911		THOMPSON, NORMAN VIVIAN, 251 Shaftesbury Place, Gateshead-on-Tyne.
1910	†	WEST, TOM, M.Sc., 157 Congregation Street, Montreal, Canada.
1912		WHITELEY, WILLIAM, 22 Myrtle Terrace, Sowerby Bridge, Yorkshire, W.R.

A

TOPOGRAPHICAL INDEX

TO

MEMBERS

OF THE

INSTITUTE OF METALS

RESIDENTS IN GREAT BRITAIN

ENGLAND

Abbey Wood—
Smith, H. M.

Aldridge—
Tucker, P. A.

Altrincham—
Johnson, A. L.

Alvechurch—
Wiggin, A. H.

Barrow-in-Furness—
Ayers, Eng.-Capt. R. B.
McKechnie, J.
Randall, Eng.-Lieut.
C. R. J.
Roberton, C. G.
Weeks, H. B.

Bedfont—
Hewitt, Prof. J. T.

Bedford—
Allen, W. H.
Robertson, W. H. A.

Birkenhead—
Bevis, R. R.
Carter, G. J.

Birmingham—
Allely, W. S.
Allen, T. J. W.
Bamford, C. C.
Barker, J. H.
Barnard, G.
Barwell, C. H.
Bedford, C. Y. R.
Bill-Gozzard, G.
Boeddicker, G. A.
Booth, C. R.
Brockbank, J. G.
Canning, T. R.
Dale, R. D.
Dugard, G. H.
Dugard, H. A.
Earle, J. W.
Fisher, H. J.
Gower, F. W.
Griffiths, H.
Heckford, A. E.
Hughes, J.
Hughes, T. V.
Jacobs, H.
Johnson, F.
Jude, A. A.
Keeling, A. D.
Kemp, J. F.
Leigh, C.
Levi, C. J.

Birmingham (*cont.*)—
MacIntosh, J. R.
McKechnie, A.
Mapplebeck, E.
Mapplebeck, E. P. W.
Meyrick, L. J.
Mills, H.
Mills, J. H.
Mitton, T. E.
Muntz, Sir G. A.
Poppleton, G. G.
Rigby, R.
Russell, C. A.
Sanders, A.
Sheppard, R. M.
Silvester, H.
Sjögren, J. F.
Taylor, C.
Taylor, J. S.
Titley, A.
Tucker, A. E.
Westwood, A.
Williams, H. W.

Bolton—
Ryder, T.

Bournville—
Tidsall, E.

Bury—
Holt, H.

Cambridge—
Heycock, C. T.
Whipple R.

Chatham—
Liversidge, Eng.-Com.
E. W.

Cheadle—
Bolton, E. J.

Cheshunt—
Woodhouse, H.

Chorlton-cum-
Hardy—
Buttenshaw, G. E.

Chorlton-on-Med-
lock—
Macfee, R.

Colchester—
Burner, A.

Consett—
Ainsworth, G.

Coventry—
Heathcote, H. L.
Hill, E. C.
Hurren, F. H.
Nevill, R. W.
Wood, R. Sibbering-.

Croughton—
Clayton, G. C.

Darlington—
Raven, V. L.
Rowley, E. W.

Derby—
Archbutt, L.
Millington, E.

Didsbury—
Bedson, J. P.
Wilson, O. E.

Dorridge—
Baylay, W. L.
Wilson, J. H.

Dunston-on-Tyne—
Evans, S.

Eastbourne—
Mallisont, G.

Eccleshall—
Wiggin, Sir H. A.

Edgbaston—
Allen, J. H.
Brown, C. A. J.
Coe, H. I.
Ellis, O. W.
Gibson, H.
Hudson, O. F.
Lacy, W. Y.
Morcom, E. L.
Player, W.
Turner, A.
Turner, Prof. T.

Enfield Highway—
Klein, C. A.

Epping—
Woore, H. L. L.

Erdington—
Clark, W. E.
Harrison, J. S.
Rider, J. J.
Strange, H.

Eskmeals—
Wheeler, R. V.

Fleet—
McLaurin, Eng.-Com. J.

Garston—
Davies, P., Jun.

Gateshead-on-Tyne—
Thompson, N. V.

Gosforth—
Williams, H. G.

Gravelly Hill—
Wilkes, J.

Halesworth—
Rush, Eng.-Com. H. C.

Hall Green—
Gibbs, L.

Handsworth—
Dobbs, E. W.

Harborne—
Aston, H. H.

Harlington—
Harris, T. R.

Harpenden—
Bradley, B.

Hartlepool—
Clark, G.

Hayle—
Pearce, G. B.

Hebburn-on-Tyne—
Sutherland, J.

Horwich—
Hughes, G.

Huddersfield—
Hopkinson, F. A.

Hulme—
Rix, H.

Hyde—
Adamson, J.

Ilford—
Pottie, G.

Ilkley—
Greenwood, T.

Ipswich—
Primrose, J. S. G.

Jarrow-on-Tyne—
Brown, W. M.
Reed, J. W.

Jesmond—
White, Col. R. S.

Keswick—
Wilson, A.

Keyham—
Taylor, Eng.-Capt. C. G.

King's Heath—
Stevens, V. G.

King's Norton—
Bayliss, T. A.
Wiggin, C. R. H.

Leeds—
Fraser, K.
Radley, W. A.
Walker, H. C.

Leicester—
Brooks, J. F.
Nesbit, D. M.

Leigh—
Hirst, T. G.

Leytonstone—
Adams, G.

Little Bromwich—
Varley, J. W.

Liverpool—
Bain, J.
Bawden, F.
Bengough, G. D.
Bibby, J. H.
Crighton, R.
Dingwall, F. W.
Greenwood, H. W.
McConwell, A.
Niggemann, B. J.
Pearce, R.

London—
Appleyard, R.
Ash, P. C. M.
Bannister, C. O.
Barnard, A. H.
Becker, P.
Beer, E.
Bevis, H.
Blaikley, A.
Blount, B.
Blundell, F. H.
Bolton, T.
Boote, E. M.
Braby, C.
Brain, H. R.
Buchanan, C.
Butterfield, J. C.

London (*cont.*)**—**
Carpenter, Prof. H.C.H.
Carruthers, Eng.-Com. D. J.
Chalas, E. C.
Chambers, D. M.
Chapman, A. J.
Clark, J.
Clarke, W. G.
Constantine, E. G.
Courtman, E. O.
Cowan, G. D.
Davison, Capt. H.
Dawlings, R. M. N.
Dewar, J. M.
Dewrance, J.
Ellis, H. D.
Ely, T.
Enthoven, H. J.
Espir, F.
Evans, U. R.
Fleminger, R. E.
Francis, A. A.
Francis, R.
Gardner, H.
Garnham, F. M.
Garnham, J. C.
Gibb, A.
Girtin, T.
Gladitz, C.
Goodwin, Eng.-Rear-Admiral G. G.
Gordon, J. G.
Gowland, Prof. W.
Grazebrook, Eng.-Lieut. R.
Gregory, S. H.
Guernsey, The Rt. Hon. Lord
Gulliver, G. H.
Gwynne, N. G.
Hadfield, Sir R. A.
Hallett, J.
Ham, Eng.-Com. J. W.
Harbord, F. W.
Heap, J. H.
Heap, R. D. T.
Herdsman, W. H.
Higgs, C.
Highton, D. C.
Hodgkinson, Prof. W. R. E.
Holloway, G. T.
Hooton, A. J. S.
Humphries, H. J.
Huntington, Prof. A. K.
Hurburgh, L. H.
Hyman, W.
Jack, H. J.

London (*cont.*)**—**
Jacob, A.
Jacob, H.
Jago, W. H.
James, G. W.
Jarry, E. V.
Johnson, A. W.
Johnson, B. A.
Kaye, H.
King, E. G.
Lambert, A. R.
Lambert, W.
Lancaster, H. C.
Langenbach, O.
Lazarus, W.
Leslie, R.
Lester, W.
Letcher, W. W.
Lord, F. A. B.
Mannell, J.
Marshall, Eng. - Com. F. W.
Maw, W. H.
Mayo, C. R.
Menzies, J.
Meyjes, A. C.
Milton, J. T.
Morison, Eng.-Com. R. B.
Morrison, W. M.
Mortimer, Eng.-Com. J. E.
Noble, Capt. Sir A.
Norman, J. T.
Oakden, Prof. W. E.
Olsson, M. C.
Oram, Admiral Sir H. J.
Palmer, A. C. H.
Preece, A. H
Quin, L. H.
Quirk, G. H.
Raworth, B. A.
Redwood, Sir B.
Reid, E. S.
Richards, Eng.-Com. J. A.
Ridge, H. M.
Robinson, J. H.
Robson, O. H.
Rose, T. K.
Rosenthal, J. H.
Ruck-Keene, H. A.
Russell, S. A.
Ruthenburg, M.
Sales, H.
Schlund, L.
Scott, A. A. H.
Seaton, A. E.
Seligman, R.

London (*cont.*)—
Seligmann, H.
Siemens, A.
Simkins, A. G.
Smith, P. W.
Smith, S. W.
Smith, Sir W. E.
Spyer, A.
Storey, W. E.
Stutz, R.
Sulman, H. L.
Swift, J. B.
Tabor, H. J.
Tearoe, J.
Thomas, F. M.
Thompson, R.
Walmsley, R. M.
Warburton, F. W.
Watson, G. C.
Watson, W. E.
Watts, Sir P.
Webb, A. J.
Webb, H. A.
Whitworth, L.
Wright, C. W.

Longport—
Billington, C.

Manchester—
Andrew, J. H.
Edwards, Prof. C. A.
Hubbard, N. F. S.
Johnson, E.
Johnson, H. M.
Johnson, W. M.
Kendrew, T.
Paterson, D.
Petavel, Prof. J. E.
Rhead, E. L.
Scott, C.
Sumner, L.
Tomlinson, F.
Turnbull, N. K.
Widdowson, J. H.
Wright, R.

Meersbrook—
Barclay, W. R.

Middlesbrough—
Hall-Brown, E.
Stead, J. E.

Milnthorpe—
Mercer, J. B.

Milton—
Gwyer, A. G. C.

Morpeth—
Esslemont, A. S.

Moseley—
Brownsdon, H. W.
Rogers, H.

Newcastle-on-Tyne—
Anderson, F. A.
Bowran, R.
Browne, Sir B. C.
Cookson, C.
Duncan, H. M.
Dunn, J. T.
Gilley, T. B.
Hills, C. H.
Hogg, T. W.
Keiffenheim, E. C.
Laing, A.
Louis, Prof. H.
Mackenzie, W.
Morehead, C.
Murray, W., Jun.
Orde, E. L.
Parsons, The Hon. G. L.
Powell, H.
Ross, A. J. C.
Smith, H. D.
Stoney, G. G.
Willott, F. J.

Northallerton—
Bell, Sir H.

Northfield—
Bayliss, T. R.

Nottingham—
Bulleid, Prof. C. H.

Old Charlton—
Pearson, G. C.

Oldham—
Hall, H. P.

Olton—
Ronald, H.

Openshaw—
Law, E. F.

Openshaw, Higher—
Sharples, J.

Ormskirk—
Mount, E.

Osgathorpe—
Colver-Glauert, E.

Peterborough—
Brotherhood, S.
Bryant, C. W.
Carnt, Eng.-Com. A. J.

Plumstead—
Thorne, E. I.

Ponder's End—
Garrett-Smith, N.

Portsmouth—
Dixon, Eng.-Com. R. B.
Philip, A.
Stenhouse, T.

Prescot—
Nisbett, G. H.

Rock Ferry—
Main, Eng.-Com. R.

Romford—
Symonds, H. L.

Rotherham—
Baker, T.
Watson, F. M.

Rugby—
Parker, W. B.

Rusholme—
Hanna, R. W.
Hanna, W. G.

St. Helens—
Appleton, J.
Groves, C. R.
Quirk, J. S.

Salford—
Smith, F.

Salisbury—
Preston, P.

IRELAND

Belfast—Caldwell, R. J.

SCOTLAND

Blanefield—
Yarrow, A. F.

Cathcart—
Lang, C. R.
Weir, W.

Clydebank—
Bell, T.
Wood, Eng.-Com.W. H.

Dalmuir—
Onyon, Eng.-Capt. W.

Dumbarton—
Denny, J.
Paul, M.
Wisnom, Eng.-Com.
W. M.

Edinburgh—
Beare, Prof. T. H.
Duff, P. J.
Gibbons, W. G.

Foyers—
Eccles, E. E.
Skelton, H. A.

Glasgow—
Ash, Eng.-Com. H. E. H.
Barclay, A. C.
Beilby, G. T.
Biles, Prof. Sir J. H.
Broadfoot, J.
Buckwell, G. W.
Campion, Prof. A.
Cleghorn, A.
Crawford, W. M.
Dawson, S. E.
Desch, C. H.
Gilchrist, J.
Gracie, A.
Greer, H. H. A.
Hendry, Col. P. W.
Hood, J. McL.
Inglis, G. A.
Kidston, W. H.
Low, A. N.
May, W. W.
Morison, W.
Reid, A. T.
Rutherford, W. P.
Sharp, R. S.
Steven, J.
Stevenson, R.

Govan—
Dunsmore, G. A.
Stephen, A. E.

Greenock—
Brown, J.
Caird, P. T.
Caird, R.

Irvine—
Edmiston, J. A. C.

Kilmarnock—
Gardner, J. A.

Kinlochleven—
Bailey, G. H.
Jameson, C. G.

Kirkintilloch—
Muirhead, W.

Milngavie—
Barr, Prof. A.

Parkhead—
Paterson, J.
Paterson, W.
Paterson, W., Jun.

Renfrew—
Brown, W.

Whiteinch—
Broadfoot, W. R.

WALES

Blackpill—
Eden, C. H.

Brondeg—
Holmes, J.

Cardiff—
Read, Prof. A. A.
Thomas, H. S.

Clydach
Bloomer, F. J.

Neath—
Jenkins, I. O.

Penarth—
Vaughan, W. I.

Port Talbot—
Deer, G.

Swansea—
Corfield, J.

Swansea *(cont.)*—
Corfield, R. W. G.
Drury, H. J. H.
Mills, E.
Ruck, E.
Sinclair, A.
Vivian, H.
Vivian, The Hon. O. R.
Walters, W. L.

Tal-y-cafn—
Hussey, A. V.

FOREIGN LIST

AFRICA

TRANSVAAL

Durban—
  Taylor, W. I.

Johannesburg—
  Murray, M. T.
  Stanley, Prof. G. H.

Pietersburg—
  Hughes, G. F.

Zuurfontein—
  Connolly, J.

EGYPT

Bulak Dakrur—Pollard, W. B. | Cairo—Garland, H.

AMERICA

BRAZIL

Rio de Janeiro—Vance, R.

CANADA

Oakville—Guess, Prof. G. A. | Montreal—Stansfield, Prof. A.
  West, T.

CHILI

Callahuasi La Grande—Brühl, P. T.

UNITED STATES OF AMERICA

Ansonia—
  Jennison, H. C.

Bayonne—
  Thompson, J. F.

Bedford Hills—
  Howe, Prof. H. M.

Boston—
  Fay, H.
  Hofman, Prof. H. O.
  Little, A. D.

Bridgeport—
  Ferry, C.
  Webster, W. R.

Bridgeville—
  Clark, W. W.
  Saklatwalla, B. D.

Buffalo—
  Miller, J.
  Skillman, V.

Cambridge—
  Boylston, H. M.
  Sauveur, Prof. A.

Chicago—
  Bregowsky, I. M.

Cleveland—
  Abbott, R. R.

Depew—
  Corse, W. M.

Ithaca—
  Gillett, H. W.

Kenosha—
  Hull, D. R.

Meriden—
  Hobson, A. E.

Minneapolis—
  Hoyt, Prof. S. L.

Nebraska—
  Almond, G.

New Haven—
  Buell, W. H.

New York—
  Allan, A., Jun.
  Harris, J. W.
  Langdon, P. H.
  Ledoux, A. R.
  Malby, S. G.

Perth Amboy—
  Foersterling, H.

Philadelphia—
  Clamer, G. H.

Pittsburg—
  Tiemann, H. P.

Schenectady—
  Capp, J. A.
  Whitney, W. R.

Waterbury—
  Bassett, W. H.
  Price, W. B.

Watertown—
  Nead, J. H.

West Lynn—
  Dawson, W. F.

ASIA

INDIA

Calcutta—
  Redding, F. C.

Camp Kunigal
    (Mysore)—
  Rao, S. R.

Dum Dum—
  Sitwell, Capt. N. S. H.

Ishapore—
  Crossley, P. B.

Kalimati—
  McWilliam, Prof. A.

Naini Tal—
  Grimston, F. S.

JAPAN

Tokyo—Tawara, Prof. K.

AUSTRALASIA

NEW SOUTH WALES

Sydney— Hankinson, A.

NEW ZEALAND

Wellington—Stewardson, G.

VICTORIA

Melbourne—Danks, A. T.

EUROPE

AUSTRIA-HUNGARY

Budapest—Rejtö, Prof. A.
Schleicher, A. P.
Weiss, E.

Ctépel—Rosambert, C.

Vienna—Münker, E.

BELGIUM

Brussels—
Féron, A.

Gentbrugge—
Tertzweil, L.

Ghent—
Carels, G. L.
Primrose, H. S.
Renaud, V.

Herstal-près-Liége—
Andri, A.

Hollogne-aux-Pierres
Boscheron, L.

Liége—
Rasquinet, A.

Merxem-lez-Anvers—
Kamps, H.

FRANCE

Montluçon—
Charpy, G.

Paris—
Cardozo, H. A.

Paris (*cont.*)—

Garfield, A. S.
Guillemin, G.

Paris (*cont.*)—

Guillet, Prof. L.
Le Chatelier, Prof. H.

GERMANY

Aachen—
Borchers, Prof. W.
Wüst, Prof. F.

Altena—
Ashoff, W.

Berlin-Grunewald—
Guertler, W. M.

Essen-Ruhr—
Goldschmidt, H.

Frankfurt-am-Main—
Beer, L.
Heberlein, F.
Landsberg, H.
Speier, L.
Stockhausen, F.

Hessen-Nassau—

Heusler, F.

Mülheim-am-Rhein—

Steven, C.
Zapf, G.

RUSSIA

Perm—Tyschnoff, W.

St. Petersburg—Belaiew, Capt. N. T.
Saposhnikow, Prof. A.

SPAIN

Bilbao—
  Collie, C. A.

Carril—
  Lessner, C. B.

Sevilla—
  Hamilton G. M.

SWEDEN

Finspongs—
  Forsstedt, J.

Gothenburg—
  Sjögren, A. S.

Stockholm—

  Benedicks. Prof. C. A. F.
  Forsberg, E. A.

Westerås—

  Falk, E.

SWITZERLAND

Zürich—Frey, J. H.

INDEX

A.

B.

C.

D.

H.

M.

S.

T.

X.

Z.

Form A. *(Membership Application.)*

INSTITUTE OF METALS.

Founded 1908. *Incorporated 1910.*

To the Secretary,

  I, the undersigned..............................,...................., being of the required age and desirous of becoming a.....................Member of the INSTITUTE OF METALS, agree that I will be governed by the regulations of the Association as they are now formed, or as they may be hereafter altered, and that I will advance the interests of the Association as far as may be in my power ; and we, the undersigned, from our personal know- , ledge, do hereby recommend him for election.

   Name in full...

   Address..

   Business or Profession....................................

   Qualifications............. ....

   ....

   Signature..

   Dated this..............day of..................., 191 .

   .... ⎫
   .... ⎬ Signatures of three Members.
   ......:................................... ⎭

   The Council, having considered the above recom-

mendation, present Mr........................to be Balloted for   To be filled up by the

as a....................Member of the INSTITUTE OF METALS.   Council.

   ....

CAXTON HOUSE,   *Chairman.*
  WESTMINSTER,. S.W.,

Dated this.................day of.................191......

  [FOR QUALIFICATIONS OF MEMBERS, SEE SECTION 1, OTHER SIDE.]

 (It would be a convenience if the Candidate's Card were sent with this form.)
 XI.

EXTRACTS FROM THE RULES.

(MEMORANDUM AND ARTICLES OF ASSOCIATION.)

SECTION I.—CONSTITUTION.

Rule 4.—Members of the Association shall be either Honorary Members, Fellows, Ordinary Members, or Student Members.

Rule 5.—*Ordinary Members* shall be more than twenty-three years of age, and shall be persons occupying responsible positions.   They shall be :—
    either (*a*) persons engaged in the manufacture, working, or use of non-ferrous metals and alloys ;
    or (*b*) persons of scientific, technical, or literary attainments connected with or interested in the metal trades or with the application of non-ferrous metals and alloys.

Student Members shall be more than seventeen years of age, and shall not remain Student Members of the Association after they are twenty-five years of age, and shall be :—
    either (*a*) Students of Metallurgy ;
    or (*b*) pupils or assistants of persons qualified for ordinary membership whether such persons are actually members of the Association or not.

Student Members shall not be eligible for election on the Council nor entitled to vote at the Meetings of the Association.

SECTION II.—ELECTION OF MEMBERS.

Rule 6.—Applications for membership shall be in writing in the form marked '' A,'' and such application must be signed by the applicant and not less than three members of the Association.

Rule 7.—Such applications for membership as Ordinary Members or Student Members as are approved by the Council shall be inserted in voting lists.   These voting lists will constitute the ballot papers, and will specify the name, occupation, address, and proposers of each candidate. They shall be forwarded to the members for return to the Secretary at a fixed date, and four-fifths of the votes recorded shall be necessary for the election of any person.

Every such election shall be subject to the payment by the applicant of his entrance fee and first annual subscription, and he shall not become a member of the Association nor be entered on the Register of Members until such sums are actually received from him.   In the event of his failing to pay such sums within the time specified in the notification to him of his election, his election shall be void.

Rule 8.—Upon election under the preceding Article the Secretary shall forward to the applicant so elected notice thereof in writing in the form marked '' B.''

Rule 9.—In the case of non-election, no mention thereof shall be made in the minutes.

SECTION VI.—SUBSCRIPTIONS.

Rule 28.—The subscription of each Ordinary Member shall be two guineas per annum, and of each Student Member one guinea per annum.   Ordinary Members shall pay an entrance fee of two guineas each, and Students an entrance fee of one guinea each.

Rule 29.—Subscriptions shall be payable in advance on July 1st in each year, save in the case of Ordinary Members and Student Members elected under Clauses 6 and 7 hereof, whose entrance fee and annual subscription shall become payable in accordance with the notification to them of their election.   Every subscription shall cover the period down to the 30th of June next following, and no longer.

Rule 30.—Subject to the provisions of Clause 7 hereof, any member whose subscription shall be six months in arrear, shall forfeit temporarily all the privileges of the Association.   Due notice on the form following marked '' C '' shall be given to such member, and if such subscription remains unpaid upon the date specified for payment in this notice, the Council may remove such member from the Register of Members of the Association, and thereupon any member whose name is so removed shall cease to be a member thereof, but shall nevertheless remain liable to the Association for such arrears.